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SOCCER INJURIES
VS
JOINT RANGE OF MOTION & MUSCLE BALANCE

BY

CARLOS EMÍLIO LADEIRA

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The undersigned certify that they have read, and recommend to The Faculty of Graduate Studies and Research for acceptance , a thesis entitled "SOCCER INJURIES VS JOINT RANGE OF MOTION AND MUSCLE IMBALANCE" submitted by Carlos Emílio Ladeira in partial fulfillment of the requirements for the degree of Master of Science.

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Abstract

Sixty two players of the Edmonton District Soccer Association were evaluated for range of joint motion (ROM) of the lower extremities and hamstrings/quadriceps strength balance before one summer season. Muscle balance was evaluated on the Cybex II® dynamometer at 30^0/s and 300^0/s. ROM was evaluated for hip flexion, knee flexion and ankle dorsi-flexion with the Myrin Goniometer® and for hip abduction with an international standard goniometer. Soccer players were followed prospectively for injuries during the season. The injuries observed during the season were correlated to the pre-season physical evaluation.

Twenty two injuries were recorded during the season. Knee sprains, ankle sprains, and hamstring strains were the injuries most often seen. Hamstring strains affected players who had poor hamstring flexibility and hamstrings which were very strong relative to the quadriceps when measured isokinetically at 30^0/s and 300^0/s (muscle imbalance). Knee sprains affected players who had quadriceps which were much stronger than the hamstrings when measured isokinetically at 30^0/s (muscle imbalance). Ankle sprains affected players with tight calf muscles. Violation of soccer rules (tackles) caused most knee sprains. Hamstring strain recurrence was very high (40%), probably because of the poor injury rehabilitation knowledge of the players and coaches.

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Table of Contents

Chapter Page

I) Introduction

1.1 Soccer as a Sport 1

1.2 The Problem 2

1.3 Purpose of the Study 3

1.4 Limitations of the Study 6

1.5 Delimitations of the Study 6

1.6 Definitions of Terms 7

1.7 Research Hypotheses 9

II) Literature Review

2.1 The Medical Aspects of Soccer Injuries 10

2.2 Evaluation of Etiological Sports Injury Factors

2.2.1 Hypermobility 19

2.2.2 Hypomobility 24

2.2.3 Muscle imbalance 27

2.3 Summary 29

III) Methodology

3.1 Sample Selection 31

3.2 Study Design 31

3.3 Equipment

3.3.1 The International Standard Goniometer 34

3.3.2 The Goniometer Myrin® 35

3.3.3 The Cybex Dynamometer® 36

3.4 Procedures

3.4.1 Flexibility Testing 37

Chapter Page

3.4.2 Strength Testing 39

3.4.3 Injury Report System 41

3.5 Statistics 42

IV) Results

4.1 Pilot Studies 44

4.2 Players Characteristics and Physical Evaluation 45

4.3 Soccer Injuries 47

4.4 Correlation: Injuries vs Physical Evaluation

4.4.1 Soccer Injuries vs Flexibility 50

4.4.2 Soccer Injuries vs Muscle Strength Balance 52

V) Discussion

5.1 Soccer Injuries 56

5.1.1 Injury Incidence and Injury Location 57

5.1.2 Injury Nature 58

5.1.3 Injury Circumstances 60

5.2 Soccer Injuries vs ROM 62

5.2.1 Strains and Overuse Injuries vs Hypomobility 62

5.2.2 Ankle Sprains vs Hypomobility 64

5.2.3 Knee Sprains vs Hypermobility 65

5.3 Muscle Balance vs Injuries 66

5.4 Clinical Implications and Future Reasearch 68

5.5 Medical Implications for Canadian Soccer Community 70

IV) Conclusion 73

Bibliography 75

Appendices Page

A) Injury Report System 81
B) Consent Form 83
C) Normative Data 85
D) Gravity Correction 87
E) Cybex Calibration 89
F) Raw Data 91

List of Tables

Table **Page**

1 Pilot Study Nº 1. Reliability Results 45

2 Pilot Study Nº 2. Reliability Results 45

3 Players Characteristics 46

4 Flexibility Measurement Res...46

5 Hamstrings/quadriceps strength ratio measured at 30°/s and 300°/s 47

6 Soccer injuries over a summer season 48

7 Soccer Injuries Characteristics 49

8 Hip flexion vs injuries in soccer..51

9 Hip abduction vs injuries in soccer 51

10 Knee flexion vs injuries in soccer 52

11 Ankle dorsi-flexion vs injuries in soccer 53

12 Ankle dorsi-flexion vs knee sprains in soccer 53

13 Hamstrings/quadriceps strength ratio at 30°/s vs injuries in soccer 55

14 Hamstrings/quadriceps strength ratio at 300°/svs injuries in soccer 55

15 Normative strength balance ratio 86

16 Cybex Calibration 90

List of Figures

Figures Page

1 Motions allowed at the knee joint 21

2 Biomechanical model of a tension/muscle length curve 24

3 The standard goniometer (TEC, Clifton, New Jersey) 35

4 The Myrin Goniometer® (Lic, Rehab, Solna, Sweden) 36

5 Subject positioning for measurement of hip flexion 38

6 Subject positioning for measurement of hip abduction 38

7 Subject positioning for measurement of knee flexion 40

8 Subject positioning for measurement of ankle dorsi-flexion 40

9 Subject positioning for measurement of knee muscle strength 42

10 Cybex Chart Recorder 88

CHAPTER 1

INTRODUCTION

1.1 Soccer as a Sport

Soccer is a popular sport worldwide.[1-28] The sport can be played indoors or outdoors. In male outdoor soccer, which was considered in this research, one adult team usually starts a match with 11 players. Generally, only two substitutions are allowed during a official match. Among the 11 players, only the goalkeeper can touch the ball with the whole body, including the hands; while the other ten athletes can use their feet, trunk, and head, but never the upper extremities, to play. Outdoor soccer is usually played on a grass field of maximum 68 m wide and 105 m long.[19] The match has two halves of 45 minutes, and a break of 15 minutes between the halves.

Despite being a contact sport, many players hurt in soccer are not injured by an intentional tackle or kick. This lack of intentioned injuries results because, according to soccer rules, a player can only take the ball from his adversary without intentionally neutralizing him, otherwise the player who neutralized his adversary would make his team be penalized for the infraction.

In terms of activity level, the sport has a hybrid intermittent nature. With minimal rest periods, the players sprint distances (10 to 25 m, for a total of 500 m) at high speeds and cover (jog and walk) substantial areas (5 to 12 Km) during the match.[20] Thus, soccer requires both sudden bursts of exertion (anaerobic energy) together with subsequent periods of moderate activity (aerobic energy). In addition to the strenuous effort, the players need a high degree of technical skill and agility to control the ball while running and passing, so that, they can dribble around the opponents and shoot at the goal.[19, 20] The physical work and nature of the sport contribute to a high incidence of injuries in the lower extremities of soccer players.

1.2 The Problem

Soccer is the most popular sport in the world.[1-6] The enthusiasm for the sport has reached North America in the last 18 years.[1, 2, 4-6] As the popularity of soccer has increased, the number of injuries seen in this activity has also risen. With such popularity, many studies have been published concerning the medical aspects of soccer injuries.[1-27] However, few publications have been written concerning soccer injury prevention through pre-season evaluation of musculoskeletal discrepancies (such as muscle tightness, imbalance, or weakness).[3, 11, 17, 18]

According to the current literature, 60 to 88% of all adult male soccer injuries were localized in the lower extremities.[1, 2, 6-9, 13, 15, 23-26] Among the injuries, muscle strains and ligament sprains were the most commonly seen regardless of age.[1-8, 12, 13, 23, 24, 26, 27] Ligament sprains were responsible for almost one third of all lesions and were more often seen in the ankle followed by the knee.[1-13, 15] In adult male soccer, not only did muscle strains have an incidence from 20% to 30%,[2, 3, 7, 8, 13] but some authors reported a high incidence (30%) of overuse injuries as well.[3, 9] Muscle strains and overuse injuries were more often seen in the hamstrings, quadriceps, hip adductors, and triceps surae.

Compared with other contact sports such as North American football or rugby, soccer injuries were less serious and less expensive.[2, 6, 7, 16] However, due to the popularity of the game, soccer injury costs have increased steadily in the last 18 years. Roaas and Nilsson[7] reported that Norwegian soccer players in five years lost 91,500 days of work, with substantial economic consequences for the athletes. In the United States, Prichett[16] reported the average of US$ 127.29 (medical costs) for any student injury in high school soccer. The average cost for severe lesions was about US$ 285.00. Besides the medical costs, the students probably lost time from school, which further increased their loss. In France, where the popularity of soccer is extremely high, over one year, it was estimated that US$ 20,000,000.00 was lost or paid out due to soccer injuries (including medical costs, insurance coverage for days lost from work and for morbidity).[24]

1.3 Purpose of The Study

One of the best ways to solve the problems associated with soccer injuries would be through prevention. The best way to prevent sports lesions is through determination and correction of injury causes. Many epidemiological studies[2, 4-7, 12-15, 24, 26, 27] have dealt with determination of injury causes that are extrinsic to players, for exemple: poor playing equipment, poor field condition, and violation of soccer rules. However, no epidemiological study has ever evaluated soccer injuries in Canada. As soccer injury causes may vary according to playing surfaces, climatic conditions, and pace of game in different countries, it would be beneficial to Canada to have its first epidemiological research concerning soccer injuries. In addition, few studies[11, 17, 18] have tried to determine injury causes that are intrinsic to players (such as muscle tightness and muscle imbalance). Therefore, the objective of this study was to obtain epidemiological information about extrinsic causes of Canadian soccer injuries as well as to investigate player physical characteristics that may contribute to accidents in soccer.

Among injury causes, some authors[22, 28-33] have suggested that joint sprains in sports might be predisposed by hypermobility (increased range of joint motion) associated with good muscle flexibility and other authors[3, 8, 17, 28, 34, 35] have mentioned that muscle strains and overuse injuries (tendinitis and bursitis) were predisposed by hypomobility (decreased range of joint motion) associated with muscle tightness.

To date, the mechanisms through which hypermobility may predispose ligament sprains have not been explained. The knee was one of the most often sprained joints in soccer.[1-27] Very flexible muscles around the knee may allow an increase in the distraction between the articulating surfaces of the tibia and the femur. Approximation of the articulating surfaces of the femur and the tibia help to increase knee stability.[36] Hence, very flexible muscles may decrease knee stability and therefore, contribute to knee ligament tears. However, the findings that knee hypermobility contributes to ligament sprains were controversial.[28, 29] The contradictions may be due to lack of methodological approach of the tests used to evaluate joint motion in the literature,[28, 29] as no accuracy, validity, or reliability was given to support the findings that knee hypermobility predisposed knee sprains. With better instruments (including validity, reliability, and accuracy), similar research would have had much more credit.[37, 38] Therefore, further investigation was felt necessary to infer whether knee hypermobility (associated with increased muscle flexibility) could predispose knee sprains.

Besides the knee, the ankle was also among the most often sprained joints in soccer.[1-27] Unlike the knee, the muscles crossing the ankle play an insignificant role in ankle stability.[39, 40] Hence, very flexible muscles around the ankle may not affect the sprain rate of this joint. The congruency between the articulating surfaces of the ankle play an extremely important role in ankle stability.[39] In neutral and in dorsi-flexion, good congruency between the articulating surfaces of the ankle provides this joint with optimal stability. However, in plantar-flexion, the stability of the ankle is less, because of poor congruency between its articulating surfaces.[39] Hence, any factor that facilitates the positioning of the ankle in plantar-flexion may contribute the individual to ankle sprains. Hypomobility associated with triceps surae tightness may facilitate plantar-flexion positioning and therefore, contribute to ligament tears.[41,42] To date, no study has evaluated whether tight calf muscles may predispose or may not predispose the individual to ankle sprains. Thus, research to investigate if tight calf muscles predisposed ankle sprains was felt necessary.

Regarding musculo-tendon-unit injuries, several authors[1, 3, 8, 17, 18, 28, 34, 35] have reported that hypomobility associated with muscle tightness could predispose muscle strains and overuse injuries (tendinitis, bursitis, and fasciitis). In soccer, to date, only three studies investigated the hypothesis that decreased range of joint motion (ROM) could increase the risk of muscle strains, tendinitis, and bursitis. The other studies simply made suggestions. Weber and Baumann[17] investigated the relationship between muscle shortening and knee pain. Although there was a higher percentage of knee pain related to decreased ROM, no statistically significant difference was found to support the results. Ekstrand and Gillquist,[8] in a retrospective study, did not find a statistically significant relationship between muscle tightness and injuries. However, in a better designed prospective study,[3] which allowed better control of the study intervening variables and direct determination of injury incidence, they found that muscle tightness was significantly correlated to injuries. To the knowledge of the present author, the last study was the only one in the literature which reported muscle tightness significantly associated with soccer injuries. Therefore, the relationship between muscle tightness and injuries (muscle strains and overuse injuries) in soccer was felt to be further investigated.

In addition to sports injuries associated with range of motion, muscle strength imbalance was also said to predispose individuals to strains and sprains. Knee sprains and thigh strains were reported to be related to abnormal hamstrings/quadriceps strength ratio.[3, 10, 11, 17, 18, 43-45] Ekstrand and Gillquist[3] and Agre and Baxter[18] found no statistically significant relationship between muscle imbalance (when measured isokinetically at 30^{0}/s and 180^{0}/s) and soccer injuries. As few researchers investigated the hypothesis that imbalance in hamstrings/quadriceps ratio might cause thigh strains and knee ligament injuries, further research into this topic was thought to be useful. Inasmuch, as knee joint motion speed was reported to reach 573^{0}/s (10 rad/s) in sprinting,[46] and as soccer requires high running speeds,[18, 19] testing at 300^{0}/s was thought to be more functional for soccer players than at 30^{0}/s and at 180^{0}/s.

Therefore, the purpose of this study was:

(a) To obtain epidemiologic information about injury characteristics (incidence, location, nature) and circumstances (game or practice, direct injury or indirect injury, severity) in Edmonton amateur soccer.

(b) To determine if hypomobility associated with muscle tightness in the ankle, knee, or hip predisposed a soccer player to muscle strains and overuse injuries (tendinitis and bursitis) respectively at each joint where the tightness had been found.

(c) To determine if tight calf muscles predisposed a soccer player to ankle ligament sprains.

(d) To determine if hypermobility associated with good muscle flexibility around the knee predisposed a soccer player to ligament sprains at this joint.

(e) To determine if imbalance in the hamstrings/quadriceps strength ratio predisposed a soccer player to knee ligament sprains and thigh strains in outdoor soccer.

1.4 Limitations of The Study

1. The study was limited to the accuracy and validity of the Myrin Goniometer® (Lic Rehab, Solna, Sweden) and the transparent standard goniometer® (TEC, Clifton, New Jersey). The former is accurate within two degrees and the latter is accurate within one degree acccording to the manufacturers.
2. The study was limited to the accuracy and validity of the Cybex II® isokinetic machine (Lumex Corporation, Bay Shore, New York).
3. The study was limited to the reliability of the author in measuring muscle peak torque and ROM.

1.5 Delimitations of The Study

1. A small sample size of 62 amateur male senior soccer players (ages: 17 to 35 years old) was used in the study.
2. Only outdoor soccer (grass field as a playing surface) was considered.
3. Only musculoskeletal discrepancies related to ROM and to muscle strength at the knee were considered. Any other musculoskeletal disorder was not taken into consideration in the pre-season evaluation.

4. Hamstrings/quadriceps strength ratio was measured with the Cybex II® isokinetic apparatus at 30°/s (the speed which most authors consider strength imbalance to avoid sports injuries[43-45, 47-49]) and 300°/s (the closest joint motion speed required in soccer which can be set on the Cybex II).[45]
5. Range of joint motion was measured with the Myrin Goniometer® and a standard goniometer.[37, 38] The ROM was measured only for the hip (flexion, abduction, extension), knee (flexion/extension), and ankle (dorsiflexion) because, these joints as well as the muscles crossing them (the quadriceps, hamstrings, triceps surae, and hip adductors) are more often injured in soccer.[1-27]
6. Injuries were recorded by the author of the study. The author was in contact with the soccer coaches weekly and in case of any injury, the athlete was interviewed personally.[1, 50]
7. The author was responsible for recording the injuries observed during the season.[1, 50] Injury nature and localization were considered as shown in the injury report system (Appendix A).
8. As the players did not have any team physician or therapist, the decision whether an injured athlete would return to play depended on the coach and the player.

1.6 Definition of Terms

1. Soccer injury: any medical problem which precluded the athlete from returning to the field of play on the same day of the injury or the next practice or game.[1, 50]
2. Injury severity was measured by time lost from play as follows:[1, 50] (a) mild: one to seven days time lost from play, (b) moderate: eight to 30 days time lost from play, (c) major: more than 30 days time lost from play.
3. Imbalance in the hamstrings/quadriceps ratio: any value one standard deviation from the mean of a reference group (see Chapter III, 3.2 Study Design).[18]

4. Low hamstrings/quadriceps strength ratio: any value one standard deviation below the mean of a reference group (see Chapter III, 3.2 Study Design).[18]

5. High hamstrings/quadriceps strength ratio: any value one standard deviation above the mean of a reference group (see Chapter III, 3.2 Study Design).[18]

6. Hypomobile joint motion: any value one standard deviation below the mean of the value obtained from the soccer players who participated in the current research (see Chapter III: 3.2 Study Design).[51]

7. Hypermobile joint motion: any value one standard deviation above the mean of the value obtained from the soccer players who participated in the current research (see Chapter III: 3.2 Study Design).[51]

8. Soccer players: 62 volunteers who played organized soccer in the premier division of the Edmonton District Soccer Association.

9. Muscle strain: any indirect injury to muscle caused by overstretch and/or excessive tension (contraction).[52]

10. Ligament sprain: any injury to ligaments related to stretch beyond their limit of elasticity,[53] and caused by either indirect or direct contact (when a player twists the ankle by himself, or the player is tackled or kicked respectively[10]).

11. Overuse injury: any musculoskeletal injury which had a gradual onset associated with pain and inflammation (such as tendinitis, bursitis, and fasciitis).[54]

12. Direct injury: any injury caused by a physical collision, such as a fracture when a player falls and breaks his arm or a knee sprain when a player is kicked or tackled and tears a knee ligament.[21]

14. Indirect injury: any injury that is not caused by a physical collision, such as an ankle sprain, when a player twists his ankle and tears the ligaments without any physical collision, or a muscle strain when a player is running and ruptures the musculotendinous unit.[21]

15. Injury incidence[9] $= \dfrac{\left(\dfrac{\text{total number of injuries}}{\text{total number of players}}\right)}{\text{the average of played hours for the athletes in the season}} \times 1000.$

1.7 Research Hypotheses

The following hypotheses were tested in this research:

1. Hypomobility associated with tightness in the hamstrings, quadriceps, triceps surae, and hip adductor muscles predisposed a soccer player to muscle strains and overuse injuries in these muscles.
2. Hypermobility associated with increased flexibility in the quadriceps, hamstrings, triceps surae, and hip adductor muscles predisposed a soccer player to knee sprains.
3. Hypomobility associated with tight triceps surae predisposed a soccer player to ankle ligament sprains.
4. Imbalance in the hamstrings/quadriceps strength ratio predisposed a soccer player to muscle (hamstrings and quadriceps) strains and knee sprains (more specifically: the anterior cruciate ligament, the posterior cruciate ligament, the medial collateral ligament, and the lateral collateral ligament, which are the main stabilizers of the knee).

CHAPTER II

LITERATURE REVIEW

The literature review was divided into two parts. The first part dealt with the medical aspects of soccer injuries, while the second part dealt with the importance of the evaluation of muscular strength imbalance (hamstrings/quadriceps) and range of motion (ROM) in the prevention of sports injuries (more specifically soccer).

2. The Medical Aspects of Soccer Injuries

There has been an increasing number of studies in the English language concerning soccer injuries.[1-18, 21, 23, 24] This medical interest might reflect the popularity of the game in North America in the last 18 years. While the attempt to professionalize soccer in North America has failed, the sport today is the most popular organized game in the United States.[55]

Pardon[2] (1977) observed that soccer injuries occurred more frequently in the lower extremities of the players. He reviewed other studies concerning localization (body part) and nature (fractures, strains, and sprains) of soccer injuries. From 4,264 soccer injuries, 21% of the lesions were localized to the ankle, 20% to the knee, and 15% to the thigh. However, it is difficult to make conclusions about the type of these injuries, because of the way some injuries were classified. There was a difference between strain and pulled muscle, and a difference between sprain and torn ligament, which made it difficult to compare with injuries in other studies that did not consider the previous differences. Moreover, this article was a review of the literature; where, the data were collected from medical records of other studies, without any methodological description and no injury definition. Therefore, few conclusions, such as the trend for higher incidence of injuries in the lower extremities of soccer players, might be drawn from this study.

MacMaster and Walter[6] (1978) designed a study to look at soccer injuries prospectively. Fifteen male players of one American professional team were followed for four months. Sixty injuries were recorded. From the 60 lesions, 26 injuries resulted in four days or less time lost from play. Twenty eighty (47%) injuries were muscle strains, 18 were ankle and foot sprains and three were knee ligament sprains (total of 35% of sprains). However, the sample size was very small (15 players from only one team). In addition, the study had no injury definition and no statistical analysis. Because of these methodological deficiencies, it is not possible to explain why the players in this study sustained such a high percentage of strains in relation to sprains when compared with other prospective studies.[3, 9-11, 15, 23, 26, 27] Only the trend for high incidence of strains and sprains in the lower extremities of adult soccer players, which agreed with other studies,[3, 7-11, 13-15, 23, 24] might be assumed.

Nilsson and Roaas[5] (1978) studied the rate, the nature, and the severity of soccer injuries in adolescent boys and girls. The data were obtained in the "Norway Cup" international soccer tournament, which was held during a five day period. Injury incidence was higher for girls than for boys, which is in accordance with other studies.[4, 26, 27] Older players sustained injuries more often than younger ones, a finding which other authors have similarly found.[7, 12, 26] Twelve percent of the injuries were localized to the hip or thigh, 14% to the knee, and 16% to the ankle. However, when minor injuries were included in the injury definition, only 20% of the injuries were strains and sprains. Almost 39% of the lesions were minor injuries (skin abrasions and blisters) which may have not made a player lose time from play or cause any other dramatic consequence. Thus, injury nature in this study could not be compared with studies which defined soccer injury based on time lost from play only.[3, 7-13, 26, 27] In addition, it was an unusual study in that an extremely large sample was followed for a brief but highly competitive period. One team might play two or more games on the same day, increasing the risk of injuries because of fatigue and time exposure. Also, the tournament was very short so it was difficult to observe lesions such as overuse syndromes.

Roaas and Nilsson[7] (1979) studied injuries of all Norwegian soccer players (males and females) retrospectively (the data were collected from 1970 to 1974). In Norway, all players must have insurance coverage and no team is allowed to play without paying the insurance premium. Therefore, data were collected through the insurance company. Higher soccer divisions had a higher incidence of injuries than the lower divisions. Adult players were reported to have more injuries than adolescent ones. Large economic consequences were reported for the players, as the insurance company did not cover all injury costs. However, data were collected through an insurance company and bias was introduced in the study, as only the more serious injuries were reported. Forty two percent of the injuries were fractures, because any fracture would receive coverage, while lesions like muscle strains and overuse injuries would not be often recorded, because such lesions receive less importance regarding coverage.

Sullivan et al[12] (1980) studied prospectively 1,272 youth soccer players (under 19 years old) for lesions during one spring season. Players were grouped by gender and age, which led the authors to conclude that younger players were less often injured than older ones, and girls were more frequently hurt than boys. These findings agreed with the results of other studies.[4, 5, 26, 27] Forty one percent of the injuries were to the ankle and 12% to the knee. More than 30% of the injuries were sprains, 33% were contusions, and almost 10% were strains. The low incidence of strains when compared with other studies,[3, 7-13, 26, 27] may be explained by methodological deficiencies in this study: the data (from 1,272 players) were collected by telephone with assistance of the players parents, who might not have been able to identify injury nature properly (differentiate muscle strain from muscle contusion). No overuse injury was reported, probably because of the age of the players. According to Shimidt-Olsen et al,[4] besides having a lower training intensity than older players, youth athletes are usually weaker, smaller, and are more flexible than older ones which may decrease the stress forces causing overuse injuries.

Pritchett et al[16] (1981) carried out a retrospective study emphasizing the costs of high school soccer injuries. Data were collected from insurance company files (years 1976 to 1977) for 10,634 athletes. Thirty eight percent of the lesions were sprains/strains (accounting for 25% of all injury costs). However, bias was introduced in the study, as injuries which receive more insurance coverage tended to be more often reported (overuse injuries may not be reported to an insurance company while ligament sprains or fractures may be reported).[7, 24] Therefore, no comparison can be done regarding injury nature between this study and others. Lower extremity injuries accounted for 58% of all injury costs, and the knee joint alone was responsible for 28% of all costs. The insurance company spent US$ 64,689.12 (medical costs) for 436 injuries. Besides the medical costs, the students might also have lost time from school which further increased the costs of the injuries.

Ekstrand and Gillquist[8] (1982) investigated retrospectively 180 male senior soccer players (average age 25 years) for past injuries. Sixty percent of the players had ligament sprains (41% of all lesions), 28% had overuse injuries (15% of all injuries), and 15% had muscle strains (12% of all lesions). Fifty seven percent of the sprains were to the ankle and 36% were to the knee. Among the strains, 91% were localized to the lower extremities. Of the overuse injuries, 11% were adductor tenosynovitis and 4% were Achilles tendinitis. This retrospective study presented a much higher incidence of sprains in relation to strains, while prospective studies have displayed some equality between incidence of strains and sprains.[3, 9-11, 13, 23, 26, 27] This finding might be attributed to the fact that data were collected by reviewing hospital records. Therefore, the retrospective survey might have been incomplete, because injuries which required more hospital care such as ligament sprains, might have been recorded more often than those that required minimal or no hospital care.[1] Also, injury definition was not based on time lost from play only, which made it difficult to compare this study with others which defined soccer injury by time lost from play only.[3, 9-11, 23, 26, 27] Injuries which "required medical attention" and time lost from play only were recorded.

Ekstrand et al[3, 9] (1983) carried out a prospective study (one year) to observe soccer injuries in 180 male senior players from the same IV Swedish amateur division. Eighty eight percent of the injuries affected the lower extremities. Player positions did not affect the injuries. Twenty nine percent of all lesions were sprains, 18% were strains (to the quadriceps, hamstrings, and hip adductor muscles) and 31% were overuse injuries. Regarding the localization of the lesions, 17% were to the ankle, 20% to the knee, 13% to the groin, 12% to the leg, and 5% to the back. Injury incidence for the individual player was 7.6 per 1,000 hours of practice and 16.9 per 1,000 hours of game (injuries were more often seen in games than in practices). Injury nature and localization were similar to what was reported in other prospective studies.[11, 13, 15, 23, 26, 27] One failure occurred in the process of choosing the sample. The players came from 12 different teams of the same division (each team contributing with 15 players). However, the players were chosen by the coach of each team according to their soccer skill, which might have introduced skill bias to the study.[1] In addition, the authors considered indoor and outdoor injuries together. As indoor soccer has different characteristics than outdoor soccer,[1] it would have been better to display the injuries according to the location in which the games were played (indoors or outdoors). Therefore, it is not possible to infer if the injuries reported in this study occurred either specifically outdoors or specifically indoors.

Albert[13] followed 54 male professional players prospectively (1979-1981) to observe soccer injuries. This author compared outdoor with indoor soccer injuries. Although no statistical analysis was used in the study, the results displayed an injury rate almost twice as high in outdoor soccer as in indoor soccer with different injury characteristics (localization and nature). The surface shock-absorbing characteristics and the pace of the game in indoor soccer were definitely different from outdoor soccer which might have affected the incidence, the nature, and the localization of the injuries.[1] Among outdoor injuries, 24% were localized to the ankle/foot, 17% to the knee, 10% to the groin/hip, 9% to the thigh, and 12% to the hamstrings. Among indoor injuries, 25% were to the ankle/foot, 19% to the knee, 13% to the groin/hip, 5.6% to the thigh, and none to the hamstrings. The most common injuries were sprains (outdoor: 27.4%, indoor: 28%) and strains (outdoor: 34%, indoor: 22%). Injury type and localization in this study were similar to other prospective studies in soccer.[3, 9-11, 23, 26, 27] The overall overuse injury incidence (4.3% of all injuries) were lower from that found by Ekstrand et at[3, 9-11] (around 30% of all injuries). Ekstrand et al[3, 9] presented a study with a moderate sample size, while Albert's study had a small sample size.[1] Therefore, it seems that Ekstrand presented a study more valid than that of Albert. Inasmuch as Albert reported injuries which required medical attention before the player resumed play and injuries that made a player lose one practice or game before returning to play (a confusing injury definition in that a player might have resumed play in the same game immediately after being attended), while the former recorded only injuries requiring time lost from play. Also, Albert evaluated American professional players, while Ekstrand studied Swedish amateur players. Despite the previous differences, it seems that there was no reason for the divergence between Ekstrand's findings[3] and Albert's findings.[13]

Klasen[14] (1984) conducted a survey of hospital records (1981 to 1982) to study the characteristics of acute soccer injuries in the Netherlands. Data were collected at the Trauma Department of the University Hospital Groningen; thus, probably only injuries which required almost immediate medical attention were reported. Among 1425 lesions reported, most of the injuries could be considered serious: 37.6% were sprains (25% were to the ankle and 10% to the knee), 10.8% were fractures, and 8% (52 injuries) were to the head/neck with 17 concussions. Lesions usually considered less serious, such as an overuse injury or even a muscle strain, were not reported. The sample was divided by age, which led the researchers to conclude that players below age 14 had more arm injuries than the other players (15 to 33 years old). The result that children have higher incidence of upper extremities injuries was in accordance with other studies.[4, 5, 12, 27] According to Keller et al,[1] children tend to fall more often on outstretched hands than adults, hurting their upper extremities, which may be a reason for the higher injury incidence.

Shimidt-Olsen et al[4] (1985) carried out a similar study to the one carried by Nilsson and Roaas[7] (1979). Six thousand, six hundred youth players (male and female, 9-19 years old) were followed prospectively in a five-day outdoor tournament in Denmark. The study was atypical in that the sample was studied in a highly and brief competitive period (five days, where the teams might play every day and sometimes twice per day). Girls had almost double the number of the injuries of the boys, which is in accordance with other studies.[5, 12, 27] It was suggested that the higher incidence of injuries in girls was due to their lack of soccer skill. However, a player with higher skills would tend to possess the ball for a longer time and be more exposed than the other athletes to being hurt (because the risk of being tackled with the ball would increase).[1] Older players had a higher incidence of lesions than younger ones, which agreed with many other authors.[4, 5, 7, 12, 26, 27] Twenty percent of the lesions were sprains (13% to the ankle), 10% were muscle strains, and 5% overuse injuries (according to Shimidt-Olsen et al,[4] overuse injuries seldom affect youth players). The incidence of strains and sprains was lower in relation to other prospective studies.[3, 8-11, 13, 23, 26, 27] However, injury definition included minor injuries which did not exclude the player from any practice or game. Therefore, injury incidence and injury nature in this study could not be compared with the results of other studies, where injury definition was according to time lost from play only.

Hoff and Martin[26] (1986) studied prospectively 455 youth players (under 16 years old) to evaluate the differences in injuries between indoor and outdoor soccer. Approximately 60% of the injuries (indoors and outdoors) affected the lower extremities. More than 30% of all injuries were sprains and almost 20% were strains, which were similar to most of the other prospective studies.[3, 9-11, 13, 26] The incidence of injuries reported for indoor soccer was much higher than for outdoor soccer, which is the opposite to what Albert[13] reported. However, Albert[13] studied professional soccer players, while this study evaluated children. In addition, Albert[13] defined an injury as time lost from play and requiring medical attention, while Hoff and Martin[26] (p. 232) used a confusing injury definition: "any medical problem that occurred in practice or game play which caused the player to miss all or part of the practice/game or which limited the individual's playing ability." How the individual playing ability was measured was not explained. Moreover in this study, the data were collected with a self-addressed questionnaire which the child's parents were supposed to fill in at the end of both soccer seasons (indoors and outdoors). Only 60% of the parents answered the questionnaires. The parents might also have forgotten details of the injuries by the end of each season. The parents might not have been able to identify the nature of some injuries (for example, sprains, strains, and contusions). Both Hoff and Martin[26] and Albert[13] made methodological mistakes discussed previously,[1, 26] which added in the contradiction between the authors. Thus, difference in injuries between indoor and outdoor soccer needs further investigation.

Eriksson et al[23] evaluated how aerobic capacity affected the nature and incidence of soccer injuries. Aerobic capacity (VO_{2max}) was estimated for 40 soccer players before and after a summer season. During the season, the players were followed prospectively for soccer injuries. Aerobic capacity was classified in low, average, and high, which led the authors to conclude that injury incidence was not affected by VO_{2max}, while injury nature was affected by VO_{2max}. Players with higher aerobic capacity had more overuse injuries, while players with lower aerobic capacity had more distortion injuries (sprains). The authors suggested that players with high VO_{2max} would be prone to overuse injuries due to a higher training intensity, while athletes with low VO_{2max} would be prone to sprains due to lack of muscular support elicited by fatigue. However, the players aerobic capacity might have changed during the soccer season (6 months). In addition, a small sample size (40 players) was used. Also, VO_{2max} was estimated based on a linear relation between heart rate (HR) and oxygen consumption, which might have introduced inaccuracy errors in the measurements, because HR not always follows a linear relationship with VO_{2max}.[56] Therefore, care should be taken when considering the results of this study.

Berger-Vachon et al[24] studied retrospectively soccer injuries which were reported to an insurance company in France. Data were collected from 123,175 amateur players and 6153 injuries were recorded. According to these authors, as data were collected through an insurance company, serious injuries were more often reported than mild ones.[24] However, some interesting findings were observed. Injury incidence was higher in the second half of the game when compared with the first half, which may reflect more fatigue in the second half of the game. Higher division leagues had higher injury incidence than lower ones. Roaas and Nilsson[7] have reported the same finding. There was no difference between injury incidence among player positions. Ekstrand et al[3, 9] have reported the same relationship. While Sullivan et al[12] presented data suggesting that goaltenders and midfielders had less injuries than strikers and backs. Further investigation is needed to reanalyze the previous results. In addition, soccer is a dynamic sport in which a player can act as a striker and a midfielder in the same match, which complicates injury comparisons for different player positions. Senior players had higher injury incidence and more severe lesions than adolescents. Other authors have presented similar results.[7, 14, 15] The high cost of soccer injuries was shown in this study. Over one year, it was estimated for France that US$ 20,000,000.00 were spent to cover the injuries caused by soccer in 1,300,000 amateur players. Most of the costs were due to ligament sprains causing a player to lose time from work.

Sadat-Ali and Sankaran-Kutty[15] (1987) studied prospectively soccer injuries which were referred to the King Fahd University Hospital over a year (1983) in Saudi Arabia. Fifty nine percent of the injuries affected the lower extremities. The majority of the patients were adolescents (11 to 20 years old). However, according to Sadat-Ali and Sankaran-Kutty[15] and Klaser,[14] severe injuries are usually more often reported to trauma hospitals;

thus, bias might have been introduced in the study. A high percentage of serious injuries (requiring hospitalization and follow up medical care) was reported (21% of all injuries).

Backous et al[27] (1988) followed prospectively 681 boys and 458 girls (6 to 17 years old) for five weeks (summer season) to observe soccer injuries. The aim of the study was to observe injury risks within groups organized by age, gender, and physical maturity. Seventy one percent of the injuries were to the lower extremities. Twenty seven percent of the injuries were strains and 19.4% were sprains. Seventy four percent of the sprains and strains were primarily indirect injuries (without physical contact with other players). These results are similar to the findings of other studies.[3, 4, 9-11, 13] Older players (starting at 14 years old) had higher injury incidence than younger ones and girls had higher injury incidence than boys, which agreed with many reports.[4, 5, 7, 12, 26] Quadriceps strain was the most common injury in boys. No explanation was given to explain such high incidence of quadriceps strains.

2.2 Evaluation of Etiological Sports Injury Factors.

2.2.1 Hypermobility (increased ROM)

After Nicholas[28] first reported that hypermobility raised the risk of knee sprains in American football, several authors[22, 30-33] postulated that any hypermobile person was in danger of ligament ruptures in any contact sport which required exercises at high joint motion speeds (such as soccer, basketball, lacrosse and football). The findings[22, 28-33] that joint hypermobility increased the risk of ligamentous injury were controversial. The controversy among the authors[22, 28-33] could be attributed to their common belief that joint mobility was a characteristic of the person (a trait) rather than the property of a particular joint. Joint mobility is not only a quality of the person, but it is also a property the joint.[57] The authors[22, 28-33] who believed that joint mobility was a characteristic of the person as a trait, designed a battery of tests to classify a person as hypermobile. However, this battery of tests was not the same in all studies. As well, the battery of tests designed to rate an athlete as hypermobile, could have skipped hypomobile (decreased range of motion) joints associated with muscle tightness, which might have introduced errors in the studies. Even very hypermobile athletes, such as ballet dancers, may have hypomobile joint motions associated with muscle tightness.[34] Thus, a basketball player who had hypomobile shoulders and was not evaluated for fingers mobility, but had a finger sprain associated with finger hypermobility, may have introduced errors in the studies.[30,31] A soccer player who had hypomobile fingers and was not evaluated for joint mobility in the lower extremities, but had an ankle sprain associated with ankle hypermobility, could have introduced errors in the studies.[32] As well, the authors[28, 30-32] did not consider that different sports have different joint sprain risks. In soccer, it is not meaningful to evaluate the relationship between finger mobility and joint sprains, because a soccer player very seldom sprains his/her fingers.[1-15] To study hypermobility and sprain risk, mobility should be considered in the joints at injury risk in each specific sport. Therefore, the validity of the previous studies[22, 28-33] was questionable.

In outdoor soccer, the incidence of sprains is high in the knee as well as the ankle. Knee sprains occur when the player twists the joint in fast cutting motions or when the player is tackled. In both situations, the knee is usually bent and excessively twisted with the foot firmly anchored to the ground by shoe cleats at the moment of the injury.[21, 58] The knee joint allows six degrees of freedom: three rotations (internal/external, flexion/extension, and adduction/abduction) and three translations (anterior/posterior, penetration/distraction, and medial/lateral), (Figure 1).[59] Without bending the joint (flexion/extension rotation), the knee cannot twist (internal/external rotation). The degree of internal/external rotation of the knee also depends on degree of penetration/distraction translation of the joint, the longer the distraction, the greater the rotation of the joint and the greater its instability.[59]

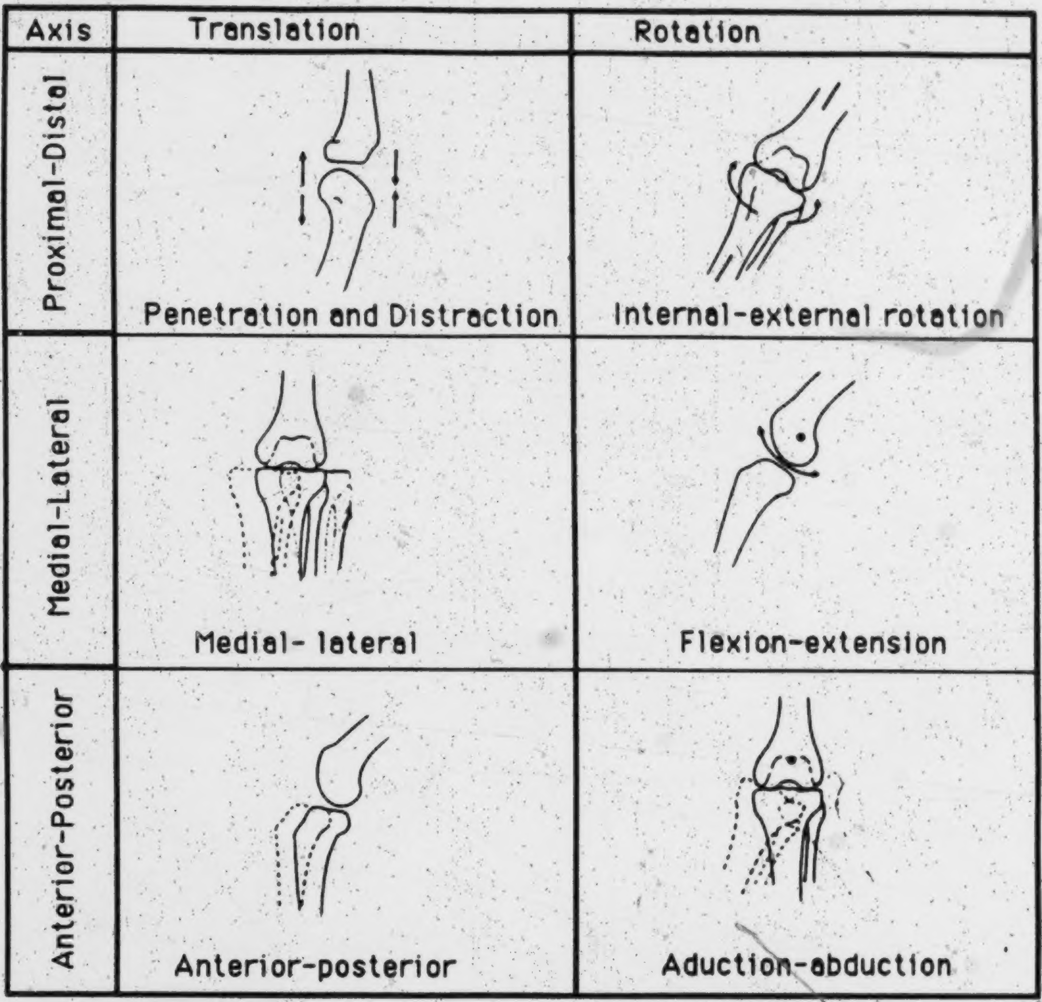
Axis
Translation
Rotation
Proximal-Distal
Penetration and Distraction
Internal-external rotation
Medial-Lateral
Medial- lateral
Flexion-extension
Anterior-Posterior
Anterior-posterior
Aduction-abduction

Figure 1 Motions allowed at the knee joint (adapted from Daniel MD and Stones ML.[37] 1988)

Muscle contraction (quadriceps and hamstrings) has been shown to greatly increase knee stability with the knee bent and twisted.[36] When the quadriceps and the hamstrings contract, the bone surfaces of the tibia and the femur approximate so that the degree of distraction translation of the knee decreases. Thus, the stability of the knee increases, because the approximation of the articulating surfaces restricts joint internal/external rotation and improves joint stability.[36] Shortened muscles around the knee may also passively restrict the distraction translation of this joint. Hence, it is possible that shortened muscles could enhance knee stability by restricting knee distraction translation. On the other hand, very flexible muscles might allow an increase in the degree of distraction translation of the knee and thereby, impair joint stability.

Nicholas[28] (1970) studied the relationship between range of motion (ROM) and knee sprains. He followed prospectively 139 professional American football players to observe the relationship between ROM and knee injuries. Nicholas[28] used five performance tests, such as "the ability to flex the spine so that the palms could touch the floor with the knee fully extended" (pp 2236) to record the players flexibility. The more performance tests an athlete could manage, the more supple the athlete was felt to be. Although no statistical analysis was used to infer the findings, the results presented the following trend: hypermobility increased the risk of ligament sprains. Fifty percent of the athletes were regarded as hypomobile players (individuals who could not perform even one of the five maneuvers), among them only 4% had ligament sprains. Athletes who performed three or more performance tests were regarded as hypermobile players and accounted for 72% of all ligament sprains. Moretz et al[29] designed a study to evaluate the validity of Nicholas tests in predicting knee injury in football players, and no correlation was found between the tests and knee injuries. Moretz et al[29] studied 150 players from different teams over two football seasons, while Nicholas[28] studied 137 players from the same team over ten years. This difference was the main discrepance between the two studies. Therefore, what might have caused the contradiction between the authors was the methodological support given for Nicholas tests; as no reliability and accuracy was given to support both studies. Flexibility might have been better recorded with a standard goniometer or a flexometer,[37, 38] and the contradiction between the authors could potentially have been solved. In addition, the tests designed by Nicholas[28] to measure knee hypermobility have questionable validity, because, some of these tests measured mobility of the hip and back rather than the knee. Hypermobility in the hip or the back does not necessarely imply hypermobility in the knee.[60] Therefore, based on Nicholas[28] tests, the relationship between knee mobility and sprains could not be validly considered.

The ankle also has a high incidence of sprains in outdoor soccer. Ligament sprains about the ankle usually occur when the player twists the joint in fast cutting motions or when the player is running on uneven surfaces.[58, 61] On both occasions, the ankle is excessively inverted and excessively internally rotated with the joint in plantar-flexion. Hence, most soccer ankle sprains affect the lateral ligaments of the joint. Hattori and Ohta[22] reported that soccer athletes had decreased ankle range of motion (inversion/eversion, internal/external rotation, and plantar/dorsi flexion) in relation to sedentary persons. From this finding, it was empirically suggested that decreased range of motion (ROM) was a beneficial anatomical adaptation for soccer players to prevent ankle sprains. Nevertheless, no information was given to explain how ankle hypomobility could protect the joint from sprains. On the other hand, MacPoil and MacGarvey[41] and Case[42] postulated that lateral ankle sprains were predisposed by hypomobility associated with shortened calf muscles. The ankle depends on its ligaments and bony structure rather than its musculature for joint stabilization.[39, 40] The stability of the loaded ankle is optimal when the joint is in the neutral position. When the ankle undergoes plantar flexion, the stability of the joint decreases considerably and its lateral ligaments are particulary vulnerable to injury.[41] The calf muscles plantar flex and invert the ankle. Tight calf muscles may facilitate the positioning of the ankle in a position of poor stability (plantar-flexion and inversion) and thereby, contribute to ligament injuries.[41, 42] MacPoil and MacGarvey[41] and Case[42] did not test the hypothesis that shortened calf muscles could predispose ankle sprains. Thus, there has not been clinical evidence to show that tight calf muscles may predispose the individual to lateral ankle sprains.

2.2.2 Hypomobility (decreased ROM)

Various studies[3, 8, 17, 28, 34, 35] have mentioned that muscle strains and overuse injuries (tendinitis, bursitis, and fasciitis) were predisposed by hypomobility associated with muscle tightness. Strains (ultimate failure of the myotendinous junction) occur with excessive muscle contraction, excessive passive muscle stretch, or both.[52] Tendinitis may be caused by repetitive load applied to the tendon tissue through muscle contraction. The load is not enough to produce ultimate failure of the tendon, but the repetitive application of this load causes tendon plastic deformation (microrupture) and inflammation.[62] Bursitis may occur because of increased tendon friction over a bursa, the friction causing damage in the tissue of the bursa with associated inflammation. Good muscle flexibility enhences the ability of the tissues to dissipate stress and accomodate impact shocks.[52, 63] In a biomechanical model of a tension/muscle length curve, it is seen that muscles with shorter length have their curves shifted to the left in relation to the curves of muscles with longer length,[64] (Figure 2). This shift means that the shorter the muscle length, the sooner the tension in the MTU will raise during active and passive joint motions.[64] Thus, when muscles have restricted flexibility, less muscle contraction and less muscle stretch are

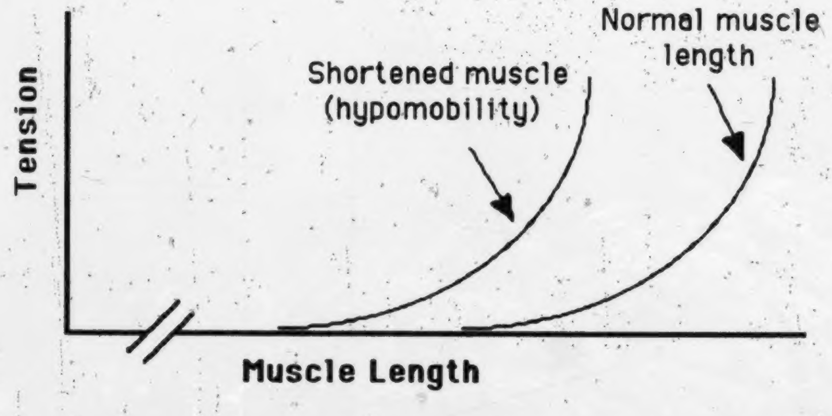

Figure 2 Biomechanical model of a tension/muscle length curve (adapted from Willians PE and Goldspink G,[64] 1978)

required to produce higher degrees of tension in the MTU. The higher the tension in the MTU, the easier musculotendinous junction rupture (muscle strain) may occur.[52] The same concept follows for tendon plastic deformation and microruptures.[62] The higher the tension in the MTU, the sooner the cumulative effects of repetitive muscle contraction will lead to fatigue and the resulting microrupture in the tendon tissue. Also, the increased tension in the MTU may apply abnormal shear forces on a bursa as a tendon slides over it, which may lead to bursitis. Therefore, good flexibility may protect not only the musculo-tendon-unit from injuries, but also the bursa.

Nicholas[28] found that muscle tightness predisposed individuals to muscle strains in football, but as mentioned previously, performance maneuvers which did not have a good methodological basis, were used to support the research. Reid et al[34] found iliotibial muscle tightness to be related to overuse injuries in the knee and hip of ballet dancers. Greipp[35] described shoulder muscle tightness which was associated with shoulder overuse injuries in swimmers.

In soccer, Ekstrand and Gillquist [3, 8, 10, 11] studied the relationship between muscle tightness (hypomobility) and injuries. In a retrospective study[8] (1982), the authors did not find a statistically significant correlation between decreased ROM and lesions (strains and overuse injuries). However, in a second prospective study (1983),[3, 10] the same authors found the correlation between muscle injuries and decreased ROM statistically significant ($P<0.05$). Among the 180 athletes studied, 44 sustained strains and overuse injuries. Of the 44 players, 34 had at least one tight muscle. However, regardless of where the tight muscle was and where the injury occurred, the tightness would be considered an injury cause. Despite any anatomical relationship, if a player sustained a hip adductor strain with triceps surae tightness, the strain would have been associated with the tightness. Therefore, the study could have been more valid if the authors had displayed the localization of the tightness and the injury in relation to each other. Hence, to date, the relationship between muscle tightness and injuries in soccer is still not conclusive. In addition, in all previous studies,[3, 8, 10, 11] the sample was not randomly chosen. Players were chosen according to their soccer skill within their teams, which probably introduced skill bias into the studies.

Agre and Baxter[18] (1987) measured the flexibility of 25 collegiate players and observed prospectively their injuries in two soccer seasons. The authors looked for asymmetry in the flexibility of the lower extremities of the players and the asymmetry correlation with injuries. Among four players who sustained low back strains, two had hamstrings ipsi-lateral length asymmetry. The researchers suggested that no quadriceps, hamstrings, or groin strains were observed because the players practiced flexibility exercises often and did not have decreased ROM. Despite the small sample size used in the study, it is possible that the flexibility exercises might have decreased the incidence of muscle strains, as Ekstrand et al[11] have already reported this finding for soccer players.

Weber and Baumann[17] (1988) measured the ROM of the knees (flexion and extension) of 95 soccer players and retrospectively observed the correlation between ROM and knee pain (related to cruciate and collateral ligament damage, as well as meniscus injury). A questionnaire to record history of knee pain was filled out by the players. Fifty nine percent of the players reported history of knee pain. Of 29 players with muscle shortening, 14 presented with knee complaints, while among 66 players without muscle contracture, only 23 had knee complaints. From the finding that a higher percentage of players with muscle shortening had past knee complaints, it was empirically suggested that muscle shortening might be a beneficial anatomical development of the muscles to protect the joints against ligament sprains. In this retrospective study, it was not possible to know whether knee pain originated from ligament injuries or from muscle shortening, because muscle contracture and knee pain might have developed after the ligament sprains as a result of the injuries. Therefore, no conclusion could be drawn from this research concerning the relationship of ROM and injury causes in soccer.

2.2.2 Muscle Strength Imbalance.

Various authors have mentioned the importance of the measurement of the hamstrings/quadriceps strength ratio in the prevention of sports injuries.[3, 43-45, 46-49, 65-68] It was suggested that imbalance in the hamstrings/quadriceps ratio might incline an athlete to knee ligament sprains as well as thigh muscles strains. However, none of the previous studies[3, 43-45, 46-49, 65-68] explained how muscle imbalance might contribute to sports injuries. When an athlete is running, there is an agonist/antagonist muscular reflex coactivation around the knee to control the movements of the joint.[65] If the agonist muscles are abnormally stronger than the antagonist ones, it is possible that the agonist muscular group could be strained because of poor antagonist coactivation to absorb the stress applied to the former. As well, the agonist muscular group could strain the antagonist group, because the latter were not strong enough to coactively oppose and resist the contraction of the former. The agonist/antagonist reflex coactivation mechanism also play an important role in the stability of the knee.[65] This coactivation mechanism allows the acting antagonist musculature at the knee to oppose a muscle contraction that endangers the ligaments of this joint.[65] Thus, when a soccer player is dribbling around opponents and the quadriceps is abnormally stronger than the hamstrings, the hamstrings will not be able to oppose the contraction of the former, which may contribute to tears in the ligaments which resist anterior translation of the knee.

Heiser et al[48] (1984) carried out a retrospective study to observe the prophylaxis of hamstrings injuries in American football players. Hamstrings strains were observed before and after the acquisition of an isokinetic apparatus (the Cybex). The Cybex isokinetic apparatus was used to detect imbalance in the hamstrings/quadriceps ratio as well as hamstrings injury rehabilitation. Among 534 players (first group) who trained without the Cybex from 1973 to 1977, there were 41 hamstring injuries with 13 recurrences, while among 564 players (second group) training with the Cybex from 1978 to 1982, there were only 6 hamstring injuries with no recurrence. The training and rehabilitation methods of the players were reported to be almost the same, except for the use of the isokinetic apparatus. There was a significant statistical difference between incidence of injuries in the first group of players and the second one. Since it was a long retrospective study (ten years), the training and rehabilitation systems of the athletes might have improved from 1973 to 1982 despite the isokinetic apparatus, even though it seems that the instrument made a difference. Therefore, the decrease in incidence of hamstrings injuries might also be attributed to the pre-season detection of hamstrings/quadriceps strength imbalance.

Grace et al[68] studied the importance of the relationship between muscle imbalance and knee-joint injuries. The hamstrings/quadriceps strength ratio was measured at 60°/s and 240°/s on an isokinetic apparatus. One hundred and seventy two American football players were tested in a pre-season evaluation. The athletes were followed prospectively for 12 weeks and knee-joint related injuries were recorded. Grace et al[68] arbitrarily defined hamstrings/quadriceps strength imbalance as "a deviation of 10% or more from the mean value for a specific side" (pp 736). No correlation was found between injuries and muscle imbalance. However, because of the way muscle imbalance was defined, one in every three football players was considered to have imbalance. Thus, the sensitivity of the definition may not have been enough to differentiate abnormal muscular imbalance among the players, which placed the validity of the study in doubt.[66] In addition, this study only evaluated the relationship between muscle imbalance and ligamentous injury. Therefore, no conclusion could be drawn from this study regarding muscular imbalance and muscle strains.

To date, only one study evaluated muscular strength imbalance and its relationship with soccer injuries. In a pre-season evaluation, Ekstrand and Gillquist[3] (1983) measured the hamstrings/quadriceps strength ratio of 180 soccer players and correlated the results with injuries. The authors prospectively studied knee ligaments and thigh musculature injuries. No relationship was found between muscular strength imbalance and the injuries. The strength ratio was measured using an isokinetic apparatus at 30°/s and 180°/s.

However, according to Leatt et al,[49] soccer requires running at higher joint motion speeds than the ones used in this study. Therefore, the measurement of muscle strength imbalance for soccer players would be more meaningful if recorded close to the functional joint motion speeds required in running (573^0/s).[46] In addition, few authors have investigated the relationship between injuries and muscle imbalance; and according to Grace,[66] further investigation is extremely important in the area to provide therapists with the knowledge for injury prevention.

2.3 Summary

There were several articles published in the English language concerning the medical aspects of soccer injuries. Many of them lack good methodological approaches (injury definition, reliable data collection, large sample, and unbiased sampling). These different approaches made it difficult to compare the results of the studies. Most soccer injuries (about 60% to 88%) occurred in the lower extremities. According to prospective studies, muscle strains and ligament sprains accounted for approximately 50% of all soccer injuries. Outdoor soccer had different injury incidence and characteristics from indoor soccer. Adult players had a higher injury incidence than youth players. Adults were stronger and faster than teenagers and children, which probably increased the forces that caused the injuries in the former.[1] Higher soccer divisions had more injuries than lower ones, probably because of the higher levels of competition in the former, in which the players were stronger and faster. Girls were injured more often than boys in soccer. It seemd that overuse injuries in adult soccer had a high incidence (about 30% of all injuries).

Serious injuries leading to death or morbidity seldom occurred in soccer. However, the treatment of the injuries were expensive. Besides, an injury could make a player lose time from school and work which further increased the economic consequences for the players and society. Soccer popularity and soccer injuries have increased in North America. However, to date no study has been published about Canadian soccer injuries. According to Keller et al,[1] soccer injuries could vary depending on the weather or the geographic region where the game was played. Moreover, the pace of game associated with soccer skill in a country could also affect the characteristics of the injuries. Thus, an epidemiologic study to determine soccer injury circumstances and characteristics in Edmonton was thought to benefit the Canadian soccer community and consequently, the Canadian society. In addition, injury prevention could be further enhanced with profiles to determine player factors (muscle balance and muscle flexibility) associated with soccer accidents.[67] Little is known about the relationship between ROM and muscle strength imbalance when related to soccer injury prevention. Therefore, an investigation of the relationship between muscle flexibility and injuries and between muscle balance and injuries was felt extremely necessary. It is always better to prevent than to remedy.

CHAPTER III

METHODOLOGY

3.1 Sample Selection

The sample of this study was gathered from the Edmonton District Soccer Association (EDSA). There were 2,000 adult amateur players registered in this association. The association had seven division levels. The author studied players who belonged to the first male amateur division only (the premier division). This division had eight teams. The coaches from two teams refused to participate in the study without giving any reason. Thus, only six teams participated in the study. In the studied teams, many players refused to participate in the research because they did not have the time to be tested, as each player had to be tested at the University of Alberta for half an hour (see 3.2 Study Design). Thus, only 69 players (an average of 11 players per team) participatated in the study.

3.2 Study Design

The players were evaluated for muscle (hamstrings/quadriceps) imbalance and ROM (hip abduction, hip flexion, knee flexion/extension, and ankle dorsi-flexion) from April 17th to May 15th, 1990. The subjects were evaluated just before the summer season began, so that the author had time to test the athletes before the games started. During the season, the players were followed prospectively for injuries. The players signed a consent form to participate in the study (Appendix B). A prospective study allowed direct determination of injury incidence and better control of the intervening variables.[69] The dependent variable of the study was soccer injuries. The independent variables were range of motion and muscle imbalance.

The inclusion criteria of the study were: (a) gender: males only, (b) soccer style and playing surface: outdoor soccer played on grass fields, (c) age: adults (17 to 35 years old), and (d) soccer level: the premier amateur division of the ESDA. The exclusion criteria included the following: (a) a player who was injured in a sport other than soccer was excluded, (b) a similar injury to the same area within two months (the same injury localization and the same injury nature) was excluded from the study,[3] and (c) a player who consecutevely missed one month or more of games and practices without having been injured was excluded from the study. The first exclusion criteria prevented the data from being affected by any sport other than soccer. The second criteria avoided an injury caused by poor rehabilitation instead of any factor related to ROM and muscle imbalance be recorded.[3] The third criteria assured a similar soccer time exposure among the players. The author asked the coaches to report any changes in the training regime of the players during the season and nothing was reported. Thus, the flexibility and the muscle balance (hamstrings/quadriceps) of the players probably did not change significantly over the period of the study (except in case of an injury).

For the purpose of this study, joint mobility was classified as: (a) hypermobile, (b) average, and (c) hypomobile, so that the relationship between ROM and soccer injuries could be studied. Hypomobility would lead to overuse injuries and muscle strains at the joint where the hypomobility was found. Hypomobile ankle-dorsiflexion would lead to lateral ankle sprains. Hypermobility around the knee would lead to knee sprains. In addition, hamstrings/quadriceps strength ratio was divided into: (a) low, (b) average, and (c) high, so that the relationship between muscle strength balance (hamstrings/quadriceps) and injuries (hamstrings strains or quadriceps strains, and knee sprains) could be studied.

The author attempted to consider joint hyper/hypo mobility according to normative data published by Ekstrand and Gillquist[8] (1982). The normal subjects were a general population. However, the normative data could not be used in this study because the data obtained in the current research were completely different from the normative data. There could have been a real difference between the population in the current research and the population in the normative data, because the latter were obtained in Sweden and the former were obtained in Canada. Different countries could offer different enviromental conditions which might adversely affect the ROM. As well, the difference between the data in this research and the normative data might have been caused by poor inter-rater reliability among the authors in the current study and the study published by Ekstrand and Gillquist.[8] Therefore, hypomobility and hypermobility was considered according to one standard deviation below and above the mean value of the soccer players who participated in the current research, respectively. Range of motion was considered as the average between the right and the left legs, as according to Öberg et al,[47] no ROM difference exists between the legs of soccer players.

Imbalance in the hamstrings/quadriceps ratio was considered as one standard deviation above (high ratio) and below (low ratio) the mean of a reference group. At 30⁰/s, imbalance was considered according to normative data published by Öberg et al.[70] The data met various standards to be used in this study: a good sample size (208 subjects), the subjects were the same gender and similar age to the individuals that were used in this study (age average: 25), and the previous study recorded strength with the same instrument which was used to record strength in this study. Besides, muscle strength balance may be sport specific and the data were collected from soccer players. To date, no normative data were published regarding strength measurement for soccer players at 300⁰/s. Thus, strength imbalance was considered according to data published by Stafford and Grana[44] for football players. The latter study met various criteria to be used in this research: a moderate sample size (60 subjects) was analyzed, male athletic individuals with similar age (ranging from 18 to 24) to the actual study were investigated, and the instrument used to record strength was the same which was used in this study. Besides, Leatt et at[49] reported hamstrings/quadriceps strength ratio (83%) for 17 teenager soccer players (age: 16 to 18) at 300⁰/s similar to the one (83.5%) published by Stafford and Grana,[44] which may indicate that no strength balance difference exist between football players and soccer players at 300⁰/s. Muscle imbalance was considered as the average between the right and the left legs;

because according to Öberg et al,[47, 70] there was no difference between strength balance of the right and the left legs on soccer players. See normative data in Appendix C.

Two examiners did all the tests together. Before the pre-season evaluation, the author did a pilot reliability study with 10 male subjects (age 17 to 39) using the Cybex II® isokinetic apparatus, the Myrin Goniometer® and a standard goniometer. The subjects were tested twice in a space of 24 hours. The procedures followed for the pilot study were the same of those used in the final study (see 3.4 Procedures below).

3.3 Equipment

3.3.1 The International Standard Goniometer® (TEC, Clifton, New Jersey) is a well known instrument to measure ROM. This goniometer was made of high impact transparent vinyl. The instrument consisted of two arms (12.25 inches long) centered on a circular dial scale (Figure 3). The circular scale gave the results in degrees (0^0 to 360^0). One arm was fixed on the circular dial, while the second (over the dial) moved independently from the former. The circular dial scale could be adjusted at various joint rotation centers with the arms positioned to measure numerous joint motion angles reliably and validly.[71, 72] This instrument was only used to measure hip abduction. As suggested by Ekstrand and Gillquist,[37] one arm of the standard goniometer was lengthened by about 28 cms to fit the long anatomic lever made by the femur during the measurement of hip abduction, see 3.4 Procedures. The arm length was increased with a transparent ruler (30 cms). The ruler was attached to the standard goniometer with an adhesive transparent tape (Figure 3). The ruler had the same width as that of the arm of the standard goniometer. The most distal end of the ruler away from the circular scale of the goniometer had its width divided in two equal parts. This reference point was used to adjust anatomical land marks with the rotation center of the goniometer.

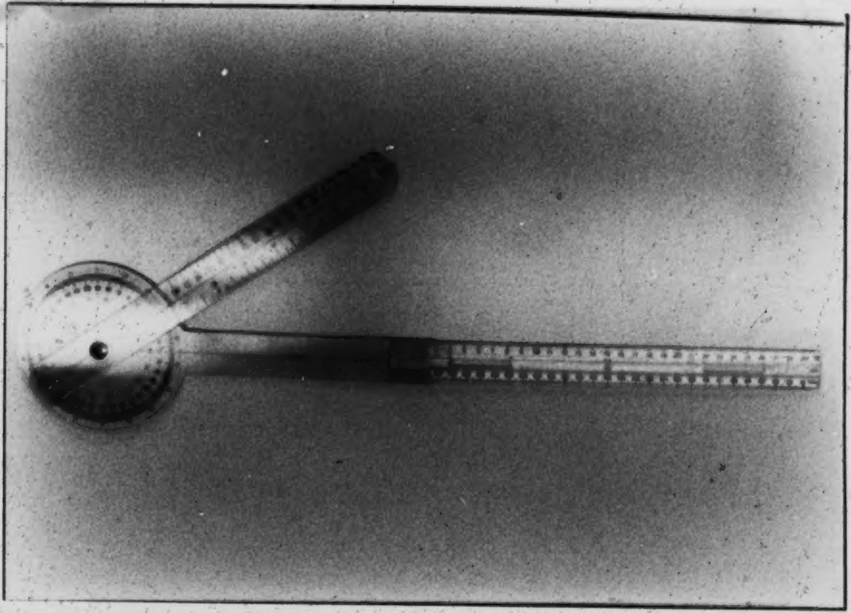

Figure 3 The Standard Goniometer (TEC, Clifton, New Jersey) modified for measurement of hip abduction.

3.3.2 The Myrin Goniometer® (Lic Rehab, Solna, Sweden) was an instrument (flexometer) designed to measure range of motion. The apparatus was a new version of the Leighton flexometer® (Leighton Flexometer, Spokane, Washington).[37, 38, 73] The instrument resembled a circular watch with a strap attachment for the limbs (Figure 4). The "watch" face had a rotating gravity needle aligned with a circular scale ranging from 0^0 to 360^0. The scale had an arrow drawn over the zero degree mark. The scale was located on a disk which rotated to align its arrow with the gravity needle. The disk locked to follow limb movements separately from the gravity pointer. Because of the gravity needle, the examiner could standardize the measurement starting position and read the results directly without assuming a joint center of rotation.[37, 74]

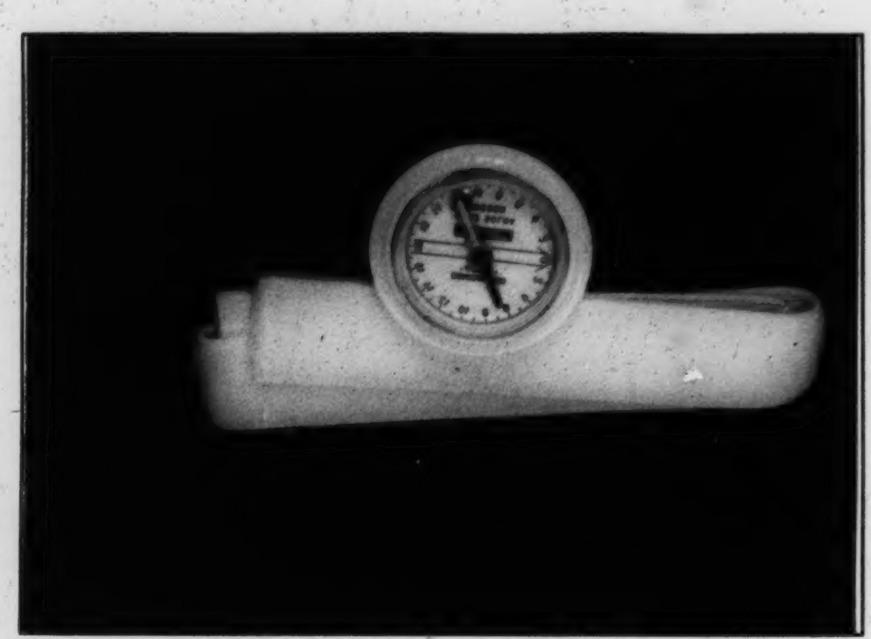

Figure 4 The Myrin Goniometer® (Lic Rehab, Solna, Sweden)

3.3.3 The Cybex II Isokinetic Apparatus® (Lumex Corporation, Bay Shore, New York) consisted of a dynamometer attached to a chart recorder which was used to record hamstrings/quadriceps strength balance. The dynamometer had an accommodating resistance which adjusted to the force applied by the subject. The chart recorder displayed (in millimeters) the force (in foot-pounds) applied by the subject and the joint angle (in degrees) at which the torque occurred. The isokinetic instrument could be adjusted to record force inputs at various dynamometer lever arm speeds: 0°/s to 300°/s. The lever arm and the tested limb did not accelerate beyond the speed adjusted by the examiner, despite the input torque applied. This mechanism, which allowed lever arm acceleration up to a certain predetermined velocity, produced measurement of muscle strength (expressed as torque) reliably at various lever arm speeds. The dynamometer recorded torques up to 360 foot-pounds.[75, 76]

3.4 Procedures

3.4.1 Flexibility Testing was performed before strength testing. The movements which were evaluated were: (a) hip abduction (b) knee flexion/extension, (c) ankle dorsiflexion with the knee fully extended, and (d) hip flexion with the knee fully extended. The last two movements were measured with the knee fully extended, because these positions were more functional in walking and running as required in soccer. In the absence of neurological and musculoskeletal disease, the previous movements were said to be restricted by ligaments and muscles.[8] The Myrin Goniometer® (discussed previously) was used to measure all movements, except hip abduction which was measured with the standard goniometer, because hip abduction was more reliably measured with the standard goniometer.[37] The subjects did a five min warm up on a bicycle ergometer with no load before the measurements to avoid muscle cramps and muscle strains.[76, 77] Each measurement was performed three times and the highest ROM observed was recorded as suggested by Ekstrand et al.[37] The measuring procedures suggested by Ekstrand et al[37] were:

Hip Flexion: The subject lay supine on a table (Figure 5). The proximal head of the fibula was marked with a pen and the Myrin Goniometer was strapped with its lower border laterally over the mark and adjusted to zero. A hard pad was placed under the lower back to restore lordosis. A second strap held the pelvis of the individual against the bench. The non-tested leg was strapped on the table. The subject relaxed the tested leg. Examiner 1 placed the ankle of the tested leg over his shoulder and lifted the tested limb with the knee fully extended, while ensuring that the knee was straight. When examiner 1 felt the knee bending, examiner 2 read the score on the goniometer and recorded the value.

Hip Abduction: The subject lay supine on the table (Figure 6). Both superior anterior iliac spines were marked with a pen. The shorter arm of the standard goniometer was placed parallel to the iliac spines over the marks. The midpoint of the patella was marked. The longer arm of the standard goniometer was adjusted vertically along the femur

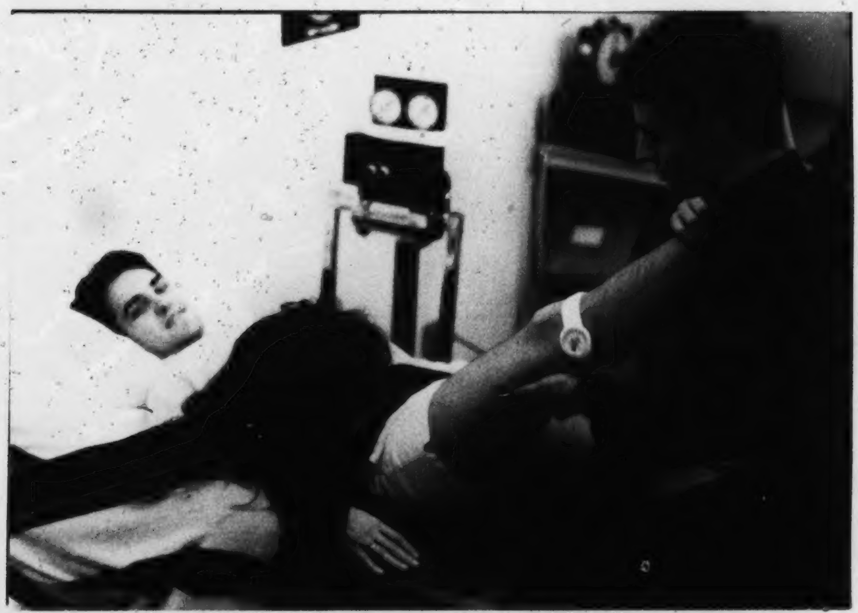

Figure 5 Subject Positioning for Measurement of Hip Flexion

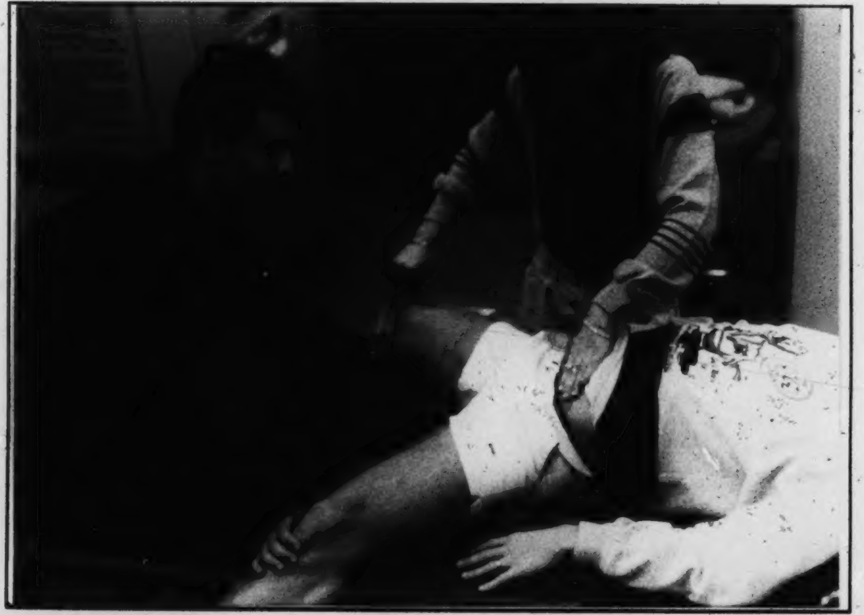

Figure 6 Subject Positioning for Measurement of Hip Abduction

to the midpoint of the patella. Each knee was bent laterally on its respective side (right or left) of the table. Examiner 1 abducted the hips of the subject maximally while examiner 2 held the arms of the goniometer in place accompanying the movement and read the results

Knee Flexion/Extension: The subject lay prone on the table (Figure 7). A strap held the pelvis of the subject against the table. The proximal base of the triangular shaped lateral malleolus was marked, the Myrin Goniometer® was placed laterally with the lower border above the mark and adjusted to zero. Only one examiner preformed this test. The knee was passively bent and when the first hip movement (flexion) occurred or the knee stopped to flex, the result was read. Hip abduction and adduction were prevented with straps over the distal femur attached around the table.

Ankle Dorsi-Flexion: The Myrin Goniometer® was adjusted in the same place used in the last measurement. The subject stood upright with the feet parallel. The goniometer was zero adjusted. Only one examiner performed this test. The examiner felt the heel on the ground with a finger. The subject placed his hands against a wall and leaned forward while keeping the tested limb fully extended at the knee and the heel in contact with the ground (Figure 8). Just before the heel lifted from the ground the score on the flexometer was read.

3.4.2 Strength Testing followed immediately after flexibility testing. The subjects had three submaximal contractions before each lever arm speed tested (30°/s and 300°/s) to familiarize themselves with the Cybex II.[79] Reciprocal consecutive concentric contractions (quadriceps followed by hamstrings) were used in the study. After the submaximal contractions, three maximum trials were performed by the individuals, and the highest peak torque observed was used in the study. The Cybex II was calibrated daily with calibration weights (see Appendix D). As the authors[44, 70] who published the normative data for this study did not mention the damping used in their studies, the damping used in the present study was arbitrarily chosen to be three. In addition, the present study evaluated the quadriceps/hamstrings ratio and not peak torque, thus the damping should not have affected the results. The paper speed used in the chart-recorder

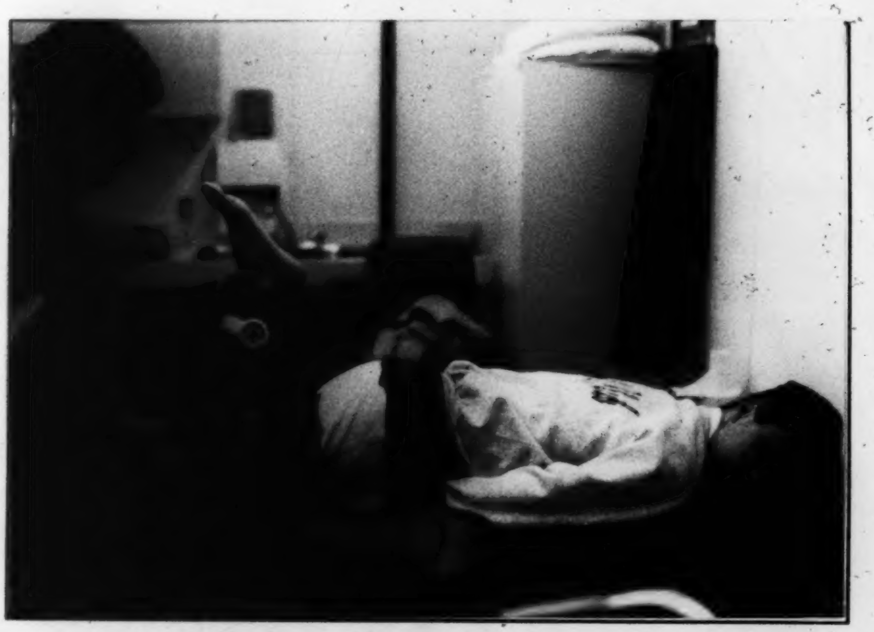

Figure 7 Subject Positioning for Measurement of Knee Flexion

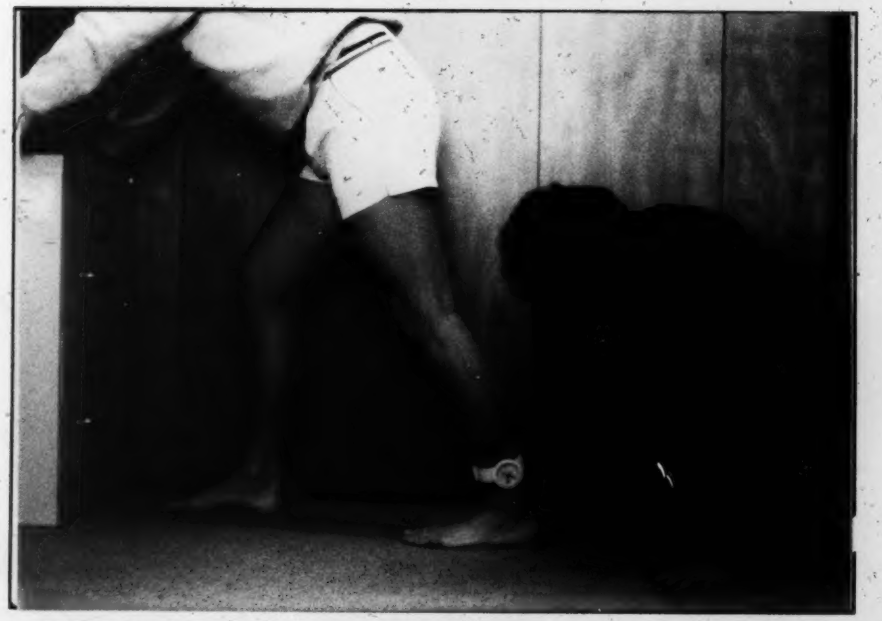

Figure 8 Subject Positioning for Measurement of Ankle Dorsi-Flexion

was 25 mm/s, so that the joint angles for gravity correction could be better observed. The Cybex chair was adjusted with the seat angle at approximately 100° (Figure 9). Straps were used to stabilize the subject against the chair: one around the pelvis, one over the distal femur, one around the chest, and one around the distal tibia about two cm above the lateral malleolus (attaching the leg to the dynamometer lever arm). A small pad was placed below the strap over the distal femur. The rotational axis of the knee was aligned with the dynamometer input shaft. The knee was bent at 90° with the tibia paralleled to the lever arm (Figure 9). The subjects were verbally encouraged to extend and to flex the knee (without pauses) as fast and as hard as possible. Muscle testing was gravity corrected at both 30°/s and 300°/s joint motion speeds. At 300°/s however, the normative data which were used in this study had no gravity correction, thus at this joint motion speed, the tests did not consider gravity compensation to ease comparison with the normative data. Procedures for gravity compensation are described on Appendix E.[75, 76, 79, 80]

3.4.3 Injury Report System. The author was in contact with all soccer coaches participating in the study weekly. In addition, the author would watch at least one soccer game per week and talk to the players before or after the games. This contact of the author with the players and coaches made a very accurate and reliable data collection possible. In case of any injury during a practice or game, the author arranged an interview with the athlete and personally inquired about the characteristics of the injury. The interview followed a report system specially designed for this study, see Appendix A. The report system was based on a study performed by Lidenfeld et al.[81]

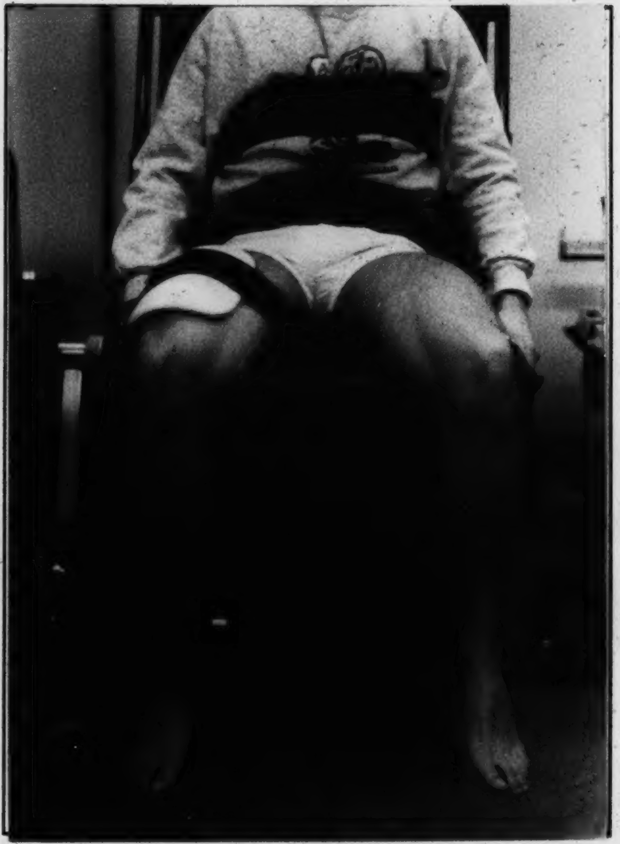

Figure 9 Subject Positioning for Measurement of Knee Muscle Strength

3.5 Statistical Analysis

Descriptive statistics (mean, standard deviation, and data range) displayed the physical characteristics of the players: weight, height, age, ROM and muscle strength ratio. Injury incidence was expressed for the individual player as: the average number of injuries (total injuries/total players) divided by the number of hours each player played during the season.[1] Injury characteristics (nature and localization) and circumstances (trauma: direct or indirect, occasion: game or practice, and severity) were shown for every accident that happened during the soccer season.

This study had to be descriptive only. It was not possible to run the X^2 to analyze the relationship between soccer injuries and the pre-season physical evaluation of the players, because of the small number of injuries that occurred during the soccer season. However, to analyze injury trends, the injuries were distributed on tables with a X^2 format: observed injuries were compared with expected injuries. The number and percentage of muscle strains, overuse injuries and ligament sprains were displayed on tables in relation to the ROM of each joint movement measured (hip abduction, hip flexion, knee flexion/extension, and ankle dorsi-flexion) (see Chapter 4 Results). The injuries were displayed in relation to joint mobility (hypomobility, average, hypermobility) as previously mentioned in this chapter (3.2 Study Design).[82, 83] The number and percentage of knee sprains and thigh strains were also presented in relation to hamstrings/quadriceps strength ratio (low, average, high) measured at 30°/s and 300°/s as previously mentioned in this chapter (3.2 Study Design).

CHAPTER IV

RESULTS

The current research attempted to determine injury causes in outdoor soccer. A questionnaire designed to obtain injury information was filled out for each accident that happened during the soccer season. In addition, each soccer player was evaluated for strength and flexibility before the beginning of the season in an attempt to predict the injuries during the season. The evaluation consisted of flexibility testing (hip abduction, hip flexion, knee flexion/extension, and ankle dorsi-flexion) and a muscle strength balance testing (the quadriceps and the hamstrings) of the lower extremities of the players. Before testing the soccer players, the author did two pilot studies to assure his reliability with the tests used in the research. This chapter presents the results obtained in the research.

4.1 Pilot Studies

Two pilot studies were carried out before testing the soccer players. In the first pilot study, ten subjects (non-soccer players, age range: 17-39) were tested for flexibility (hip flexion, hip abduction, knee flexion, and ankle dorsi-flexion) and isokinetic strength (quadriceps and hamstrings at 30°/sec and 300°/sec). The reliability of the strength testing was satisfactory (Pearson's correlation above 0.8, Table 1). However, in the flexibility testing, the reliability of hip abduction was not satisfactory (Pearson's correlation below 0.8, Table 1). Thus, the flexibility testing was repeated in a second pilot study with ten subjects (non-soccer players, age range: 17-33) to obtain better results for hip abduction (Table 2). The standard goniometer (TEC, Clifton, New Jersey) used in the research to measure hip abduction was modified based on the goniometer used in the study carried by Ekstrand and Gillquist,[37] (Chapter III, 3.3 Instruments and 3.4 Procedures). After the modification of the standard goniometer, the reliability of hip abduction was satisfactory (Pearson's correlation above 0.8, Table 2). The modification of the standard goniomenter

Table 1 Pilot Study № 1. Reliability Results (N=10).
(Pearson's Correlation)

Tests:	Measurement:	Correlation:
Flexibility	Ankle extension	0.93
	Knee flexion	0.89
	Hip flexion	0.92
	Hip abduction	0.71
Strength *	Quads 30°/s	0.97
	Hams 30°/s	0.90
	Quads 300°/s	0.91
	Hams 300°/s	0.91

* Quads= quadriceps, Hams= hamstrings, °/s = degrees per second

Table 2 Pilot Study 2. Reliability of Hip Abduction (N=10).
(Pearson's Correlation)

Tests:	Measurement:	Correlation:
Flexibility	Hip abduction	0.82

allowed better adjustment of the goniometer arms with body landmarks used in the measurement, which probably caused the improvement in the reliability of hip abduction measurement.

4.2 Players Characteristics and Physical Evaluation

Of 114 players contacted to participate in the study, 69 players volunteered to be subjects in this research (the response rate was 60%). The mean, the standard deviation, and the data range for age, height, and weight of the 69 players are presented in Table 3. Among the 69 soccer players, seven subjects were excluded from the research. One player changed his team during the season and his second team was not being studied in the research. Two players did not play in the season for two months because they went away on vacation. Four other players could not participate in the testing procedures because they were injured at the time of the testing.

The results of the physical evaluation display the measurements of the players who finished the study (total of 62 subjects). The measurements represent the average between the legs of each player. For each flexibility measurement, the mean, the standard deviation and the data range are shown (Table 4). As well, the mean, the standard deviation and the data range for the hamstrings/quadriceps strength ratio are displayed (Table 5). The raw data of strength and flexibility measurements for the lower extremities of the players are displayed in Appendix F.

Table 3 Players Characteristics, N=69
($\overline{X}$: mean, sd: standard deviation)

	$\overline{X}$	sd	Range
Age (years)	24.83	5.11	17-39
Weight (kg)	76.33	9.77	59-109
Height (cm)	177.4	7.13	165-197

Table 4 Flexibility measurement results (in degrees of joint motion) for 62 soccer players.

Joint motion	Mean	Std. Dev.	Range
Hip abduction	43.69	5.20	30 - 53
Hip flexion	61.85	7.14	44 - 78
Knee flexion	142.39	8.55	129 - 160
Ankle extension	22.15	4.93	11 - 35

Table 5 Hamstrings/quadriceps strength ratio results measured isokinetically at 30°/s and 300°/s (N=62 soccer players).

Speed*	Mean	Std. Dev.	Range
30°/s GC	0.54	0.08	0.31 - 0.72
300°/s GC	0.67	0.09	0.48 - 0.87
30°/s	0.61	0.09	0.39 - 0.81
300°/s	0.88	0.09	0.67 - 1.14

*Speed: °/s= degrees per second, GC= gravity correction.

4.3 Soccer Injuries

Twenty two injuries were observed during the summer season. The nature and the localization of the injuries are shown in Table 4.6. No player had a previous history of any similar injury to the ones observed during the season within the last two years, except a player with Achilles tendinitis. Eighty six percent of the injuries occurred in the lower extremities. Among the injuries in the lower extremities, 31.8% were sprains (four knee sprains and three ankle sprains), 31.8% were strains (five hamstrings strains and two groin strains) and 13.6% were overuse injuries (one Achilles tendinitis, one plantar fasciitis and one bursitis at the first metatarsal head, Table 6). There were six re-injuries during the season: one Achilles tendinitis, one plantar fasciitis, two hamstring strains, one groin strain, and one ankle sprain.

Among 62 players, 19 or 29% of the players suffered one or more injuries. Injuries were evenly distributed among different players ages. Every soccer team played one game (1.5 hours) per week during six months (for a total of 36 hours of soccer). According to the coaches of the Edmonton Soccer Assocation, there was about 60% game attendance for the selected 62 players. Hence, each athlete must have played an average of 21.6 game hours during the season. Thus, injury incidence for the individual player was 13.4 per 1000 game hours [(18 injuries ÷ 62 players) ÷ 21.6 hours x 1000, see formula in 1.6

Definition of Terms, Chapter I].[9, 84, 85] Regarding injury severity, 40.9% were considered as mild, 50% as moderate, and 9.1% as major (Table 7). Knee sprains were the only major injuries. Knee sprains which happened during the games occurred in the last 15 minutes of the second half. Sixty four percent of the injuries were indirect injuries (injuries not caused by a physical collision) and 36% were direct injuries (injuries caused by a physical collision). Physical contact was responsible for the major injuries observed during the season (Table 7). Of knee sprains, three involved the medial collateral ligament and one the lateral collateral ligament. Of the 22 injuries, 18 occurred in a game situation, one occurred in a practice, and three had no specific occurrence occasion with a gradual onset of symptoms (overuse injuries), (Table 7).

Table 6 Soccer injuries over a summer season (N=22).

Injuries*	Number	Percentage
Knee sprain	4	18.8%
Ankle sprain	3	13.6%
Hamstring strain	5	22.8%
Hip adductor strain	2	9.1%
Achilles tendinitis	1	4.5%
Plantar fasciitis	1	4.5%
Bursitis (1st metartasal head)	1	4.5%
Shin contusion	1	4.5%
Knee laceration	1	4.5%
Lower back sprain	1	4.5%
Nose contusion	1	4.5%
Finger sprain	1	4.5%

* Injury localization: 86.3% of the injuries occurred in the lower extremitie. Injury nature: 36.3% of the injuries were sprains, 31.8% were strains and 13.6 % were overuse injuries.

Table 7 Soccer injury characteristics.

Injury	* When occurred?		How occurred?		Severity?		
	Game	Practice	Direct	Indirect	Mild	Moderate	Serious
Knee sprain	3	1	3	1	1	1	2
Ankle sprain	3		1	2	1	2	
Hamstring strain	5			5	2	3	
Hip adductor strain	2			2	1	1	
Achilles tendinitis				1	1		
Plantar fasciitis				1	1		
Bursitis (1st metartasal head)				1	1		
Shin contusion	1		1		1		
Knee laceration	1		1			1	
Lower back sprain	1			1		1	
Nose contusion	1		1			1	
Finger sprain	1		1			1	
Percentage	72.7%	4.5%	36.4%	63.6%	40.9%	50%	9.1%

*It is not known whether the overuse injuries occurred in a game or in a practice.

4.4 Correlation: Injuries and Physical Evaluation

4.4.1 Soccer Injuries vs ROM. Four joint movements were correlated to soccer injuries, namely: (a) hip flexion, (b) hip abduction, (c) knee flexion, and (d) ankle dorsi-flexion. In order to study the relationship between injuries and flexibility, joint mobility was classified into hypomobile, average, and hypermobile (Chapter III, 3.2 Study Design).

(a) Hip flexion vs Injuries. Fourteen percent of the players had hypomobile hip flexion, 71% of the players had average hip flexion, and 14.4% of the players had hypermobile hip flexion. Of five hamstrings strains, two of the affected players had hip flexion hypomobility and three players had average hip flexion mobility (Table 8). No player with hip flexion hypermobility (ROM above 69^0) sustained a hamstrings strain. Forty percent of hamstrings strains affected players with hip flexion hypomobility (ROM below 55^0). Considering that 14.4% of the players had hip flexion hypomobility, 14.4% of the strains were expected to affect these players. However, the percentage of injuries that affected the players with hip flexion hypomobility were two and a half times greater than that which was expected. Regarding knee sprains, three affected players with average hip flexion mobility and one affected a player with hip flexion hypermobility. No player with hip flexion hypomobility had a knee sprain.

(b) Hip abduction. Twenty two percent of the players had hypomobile hip abduction, 58.1% had average hip abduction, and 19.3% had hypermobile hip abduction (Table 9). Two groin strains that occurred during the season affected players with average hip abduction. Concerning knee sprains, two affected players with average hip abduction and two affected players with hip abduction hypermobility. As only 19.3% of the players had hypermobile hip abduction, only 19.3% of knee sprains were expected to affect these players. However, 50% of knee sprains were sustained by players with hypermobility of hip abduction, which were more than two and a half times of what were expected (Table 9).

Table 8 Hip flexion vs Injuries in Soccer

Players	Hypomobility ROM <54.7^0	Average 54.7^0< ROM>69^0	Hypermobility ROM > 69^0	**ROM	
				<61.8^0	>61.8^0
Non-injured	9	44	9	29	33
Percentage	14.4%	71%	14.4%	46.7%	53.2%
Muscle strain	2*	3*	0	3*	2*
Percentage	40%	60%	0%	60%	40%
Knee sprain	0	3	1	1	3
Percentage	0%	75%	25%	25%	75%

Legend: ROM: range of joint motion, <: below, >: above, *hamstring strain, **61.8^0 is the mean value for hip flexion of soccer players.

Table 9 Hip abduction vs Injuries in Soccer

Players	Hypomobility ROM <38.5^0	Average 38.5^0<ROM> 48.9^0	Hypermobility ROM >48.9^0	*ROM	
				<43.7^0	> 43.7^0
Non-injured	14	36	12	26	36
Percentage	22.6%	58.1%	19.3%	41.9%	58.1%
Groin strain	0	2	0	1	1
Percentage	0%	100%	0%	50%	50%
Knee sprain	0	2	2	1	3
Percentage	0%	50%	50%	25%	75%

Legend: ROM: range of joint motion, <: below, >: above, *43.7 is the mean value for hip abduction of soccer players.

(c) Knee flexion: Nineteen percent of the players had hypomobile knee flexion, 62.9% had average knee flexion, and 17.7% had hypermobile knee flexion (Table 10). There were no quadriceps strains during the soccer season. Among four knee sprains, two affected players who had knee flexion hypermobility, one affected a player who had average knee flexion mobility and the other one affected a player who had knee flexion hypomobility. Fifty percent of knee sprains affected players with knee flexion hypermobility. This percentage was more than two and a half of what was expected for players with hypermobility (17.7% of sprains were expected), (Table 10).

Table 10 Knee flexion vs Injuries in Soccer

Players	Hypomobility ROM<133.8^0	Average 133.8^0<ROM>151^0	Hypermobility ROM >151^0	**ROM	
				<142.4^0	>142.4^0
Non-injured	12	39	11	33	29
Percentage	19.4%	62.9%	17.7%	53.2%	46.8%
Knee sprain	1	1	2	1	3
Percentage	25%	25%	50%	25%	75%

Legend: ROM: range of joint motion, <: below, >: above, **142.4^0 is the mean value for knee flexion of soccer players.

(d) Ankle dorsi-flexion: Seventeen percent of the players had hypomobile ankle dorsi-flexion, 71% had average ankle dorsi-flexion, and 11.3% had hypermobile ankle dorsi-flexion (Table 11). One Achilles tendinitis and one plantar fasciitis affected players with average ankle dorsi-flexion mobility. Nevertheless, these injuries affected only players who had ROM below the mean value for the group of soccer players (below 22.2^0 ankle dorsi-flexion). Of three ankle sprains, two affected players with ankle dorsi-flexion hypomobility and one with average ankle dosi-flexion mobility. Players who had hypomobile ankle dorsi-flexion sustained 66.6% of ankle sprains, which were three times more of what was expected (17.7% of sprains were expected). Regarding knee sprains, no interesting observation could be performed. Knee sprains were evenly distributed among different ankle dorsi-flexion categories (Table 12).

4.4.2 Soccer Injuries vs Muscle Strength Balance. Hamstrings/quadriceps strength ratio was measured Isokinetically at two different speeds (with and without gravity correction): 30^0/s and 300^0/s. In order to analyze the relationship between muscle balance and soccer injuries, the hamstrings/quadriceps strength ratio was classified into low, average, and high (Chapter III, 3.2 Study Design). For better comparison between the normative data and the data obtained in this study, muscle

Table 11 Ankle dorsi-flexion vs Injuries in Soccer

Players	Hypomobility ROM <17.2^0	Average 17.2^0<ROM>27.1^0	Hypermobility ROM> 27.1^0	**ROM	
				<22.2^0	>22.2^0
Non-injured	11	44	7	34	28
Percentage	17.7%	71%	11.3%	54%	45.2%
MTU Injury*	0	2*	0	2*	0
Percentage	0%	100%	0%	100%	0%
Ankle sprain	2	1	0	2	1
Percentage	66.7%	33.3%	0%	66.7%	33.3%
Total	2	3	0	4	1
Percentage	40%	60%	0%	80%	20%

Legend: ROM= range of joint motion, <below, >above, *MTU (musculo-tendon-unit injuries: one Achilles tendinitis and one plantar fasciitis. ** 22.2^0 is the mean value for ankle dorsi-flexion of soccer players.

Table 12 Ankle dorsi-flexion vs knee sprains in Soccer

Players	Hypomobility ROM < 17.2^0	Agerage 17.2^0<ROM>27.1^0	Hypermobility ROM>27.1^0	**ROM	
				< 22.2^0	>22.2^0
Non-injured	11	44	7	34	28
Percentage	17.7%	71%	11.3%	54.8%	45.2%
Knee sprain	1	2	1	2	2
Percentage	25%	50%	25%	50%	50%

Legend: ROM: range of motiom, <: below, >above, **22.2^0 is the mean value for ankle-flexion of soccer players.

strength ratio was classified with gravity correction at 30^0/s and without gravity correction at 300^0/s (Tables 13 and 14). The reason muscle strength ratio was classified without gravity correction at 300^0/s was that there were no normative data available with gravity correction to be compared with muscle strength measured at 300^0/s with gravity correction (see Chapter III, 3.2 Study Design). However, the present author believes that this lack of gravity correction did not influence the results of the study, because the correlation between muscle strength measured at 300^0/s with gravity correction and muscle strength measured at the same speed without gravity correction was very high (Pearson's Correlation: 8.88).

Hamstrings/quadriceps strength ratio at 30^0/s. Forty seven percent of the players had a low hamstrings/quadriceps ratio, 51.6% had an average hamstrings/quadriceps ratio, and 1.6% had a high hamstrings/quadriceps ratio at 30^0/s (Table 13). Among four knee sprains, three affected players with a low strength ratio and one affected a player with an average strength ratio. The percentage of sprains that affected players with low strength ratio was a little higher than that expected. Forty seven percent of sprains were expected for players with a low strength ratio. However, 75% of sprains affected players with a low strength ratio, which was one and a half times what were expected for these players. Regarding hamstrings strains and hamstrings/quadriceps strength ratio, four strains affected players with an average strength ratio and one strain affected a player with a high strength ratio. It is interesting to observe that there was one player with a high strength ratio and this player suffered a hamstring strain. In addition, the players who had their strength ratio above 60.8% (16.1% of the players) sustained 60% of strains, which was more than three and a half times of what was expected (16.1% of injuries, Table 4.12).

Hamstrings/quadriceps strength ratio at 300^0/s: Five percent of the players had a low strength ratio, 62.9% had an average strength ratio, 32.3% had a high strength ratio at 300^0/s (Table 14). No interesting relationship was observed between knee sprains and strength ratio at 300^0/s. Three sprains (75% of sprains) affected players with an average strength ratio, while 63% of sprains were expected to affect these players. One sprain (25% of sprains) affected a player with a high strength ratio, while 32.3% of sprains were expected to affect players with a high strength ratio. Concerning hamstrings strains and strength ratio at 300^0/s, one strain affected a player with an average strength ratio and four strains affected players with a high strength ratio. Thirty two percent of strains were expected to affect players with a high strength ratio and 80% of strains affected these players. Thus, the percentage of strains expected to affect players with a high strength ratio was almost two and a half times greater than what was expected (Table 14).

Table 13 Hamstrings/quadriceps strength ratio vs Injuries in Soccer (strength measured at 30^{0}/s with gravity correction)

Players	Low ratio <53%	Average 53%<ratio>68.6%	High ratio>68.6%	Ratio**	
				<60.8%	>60.8%
Non-injured	29	32	1	52	10
Percentage	46.8%	51.6%	1.6%	83.9%	16.1%
Knee sprain	3	1	0	3	1
Percentage	75%	25%	0%	75%	25%
Strain*	0	4	1	2	3
Percentage	0%	80%	20%	40%	60%

Legend: <: below, >: above, * Hamstring strain, ** 60.8% is the mean value for hamstrings/quadriceps strength ratio of the normative data.

Table 14 Hamstrings/quadriceps strength ratio vs Injuries in Soccer (strength measured at 300^{0}/s without gravity correction)

Players	Low ratio <73.5%	Average 73.5% <ratio> 93.5%	High ratio >93.5%	Ratio**	
				<83.5%	>83.5%
Non-injured	3	39	20	19	43
Percentage	4.8%	62.9%	32.3%	30.6%	69.4%
Knee Sprain	0	3	1	2	2
Percentage	0%	75%	25%	50%	50%
Strain*	0	1	4	1	4
Percentage	0%	20%	80%	20%	80%

Legend: <: below, >: above, *Hamstring strain, **83.5% is the mean value for hamstring/quadriceps strength ratio of the normative data.

CHAPTER V

DISCUSSION

The main objective of this research was to investigate etiological factors associated with soccer injuries. For this purpose, not only a physical evaluation to identify injury factors intrinsic to the players was carried out, but also a questionnaire to analyze injury factors extrinsic to the players was filled out for each accident that happened during the soccer season. The former examined the flexibility and the muscle strength balance of the lower extremities of the players and the latter obtained information regarding injury circumstances and injury characteristics for each accident. This chapter discusses the findings of the present investigation.

5.1 Soccer Injuries

Comparison between this study and other studies[2-16, 24, 26, 27, 84, 85] which evaluated soccer injuries was complicated by many factors. Retrospective studies[2, 8] often had poor estimation of injury time exposure. Hence, because of indefinite time exposure to soccer, it was difficult to compare retrospective studies with prospective ones. Prospective studies of brief tournaments,[4, 5] in which a soccer team could play more than a game in the same day, presented an unusual high injury incidence because of a high competitive soccer intensity in a short time period.[1] Thus, it was not possible to compare studies which investigated brief tournaments with this study. Investigations in which data were collected from insurance companies[7, 16, 24] and hospitals[14, 15] could not be compared with this investigation, because of the way data were collected in the current investigation. Injuries obtained from insurance companies and hospitals were often more serious than injuries observed by a coach or an athletic trainer in direct contact with the players.[14, 24] As well, studies that had an unreliable data collection (telephone survey or mailed questionnaire)[12, 26] or no injury definition[6] could not be compared with the present research, because of the methodological deficiencies in these papers. For a good comparison among studies, Keller et al[1] has recently suggested an standardization of research methods for every epidemiologic study.

Good comparison among epidemiologic studies requires that they have similar methodology. Few reviewed studies had similar methods of design, data collection, injury definition, injury severity classification, or soccer exposure calculation as the current research did. As well, few studies investigated a population that was similar to the one in the current research (senior amateur players). Thus, the results of this study could only be meaningfully compared with the results of the studies published by Ekstrand and Gillquist,[3, 9] Nielsen and Yde,[84] and Engström et al.[85]

5.1.1 Injury Incidence and Injury Location:

Twenty two injuries were recorded during the season. The injuries were distributed among 18 players (29% of the players). Injury incidence was 13.4/1000 game hours for the individual player. It was not possible to analyze injury incidence during practices, because the soccer coaches could not keep track of the training hours of the players. Nielsen and Yde[84] and Engström et al[85] published almost the same injury rates for Danish amateur players (14.3/1000 hours) and Swedish semiprofessional players (13/1000 hours) respectively. Ekstrand and Gillsquist[3, 9] reported similar injury incidence (16.9/1000 hours) for Swedish amateur players.

Eighty six percent of the injuries affected the lower extremities of the players. These results were similar to the results published by Ekstrand and Gillquist[3, 9] (88%), Nielsen and Yde[84] (84%), and Engström et al[85] (93%). Twenty two percent of the injuries affected the knee. Ekstrand and Gillquist,[3, 9] and Nielsen and Yde[84] found similar knee injury rates (20% and 16.2% respectively), while Engström et al[85] presented higher knee injury rate (33%) than that presented in the current research. The differences may be attributed to the difference in soccer level (amateur vs semiprofessional) between this study and the latter. As soccer skill level increased, the rate of major injuries usually rose.[85] Thus, as soccer level increased, the rate of knee injuries may also have risen, because knee injuries had often the highest incidence among major injuries.[3, 9, 24, 84, 85] The ankle were responsible for 13.6% of the injuries. Ekstrand and Gillquist[3, 9] found similar injury rate (17%) to the ankle. Nielsen and Yde[84] and Engström et al[85] reported higher ankle injury rates: 35% and 22% respectively. However, if considered only the number of sprains to the ankle, there was a greater similarity among the studies. All ankle injuries in the present research were sprains (13.6%). Ekstrand and Gillquist[3, 9] and Engström et al[85] found 16.7% and 15.3% of ankle sprains respectively. Thirty one percent of the injuries affected the groin/thigh area. Similar groin/thigh injury rates were reported elsewhere: 27% (Ekstrand and Gillquist[3, 9]), 20% (Engström et al[85]), and 22% (Nielsen and Yde[84]).

5.1.2 Injury Nature:

Of all injuries, 40.9% were sprains. Other authors found similar sprain rate: 29% (Ekstrand and Gillquist[3, 9]), 34% (Engström et al[85]) and 48.6% (Nielsen and Yde[84]). Forty four percent of sprains were to the knee and 33.3% were to the ankle. The percentage of sprains to the ankle was higher than that to the knee in other studies.[3, 9, 84] Ekstrand and Gillquist[3, 9] and Nielsen and Yde[84] found respectively 34% and 26.4% of sprains to the knee and 59% and 66% of sprains to the ankle. Why the number of sprains to the knee was higher than that to the ankle in the current research is not known.

Muscle strains were responsible for 31.8% of all injuries. Lower rates of muscle strains were reported in Europe: 18% (Ekstrand and Gillquist[3, 9]), 12% (Engström et al[85]) and 21% (Nielsen and Yde[84]). The reason may be that European teams had better training supervision than the Edmonton teams did. Muscle strains were said to be predisposed by poor muscle flexibility and lack of muscle warm up. The Swedish semiprofessional players,[85] with a strain rate of only 12%, had athletic trainers supervening their training. The Swedish amateur players[3, 9] and the Danish amateur players always had their coaches present during practices and games. Coaches and mainly athletic trainers could always instruct their players to warm up and to stretch before playing ball. However, the

Edmonton teams had their coaches present at all games, but not at all practices. Edmonton players could train without any supervision at all. Hence, many players might not have stretched or warmed up during the practices. In addition, sometimes before games and even in the presence of the coach, a few players would not stretch or warm up.

Three overuse injuries (a bursitis, a tendinitis, and a fasciitis) accounting for 13.6% of all injuries were observed in the present study. Among these injuries, two were related to poor shoe fit. Nielsen and Yde[84] reported similar overuse injury rate: 15.6% of tendinitis/bursitis. Engström et al[85] found a higher overuse injury incidence (33%) for semiprofessional players than that found in this study. The reason is most probably that the semiprofessional players had a higher training intensity than that of the amateur players in this study. Ekstrand and Gillquist[3, 9] also reported higher overuse injury incidence (23% of tendinitis/bursitis) than that found in this study. The reason may be attributed to the difference in the playing surfaces between this study and the latter. The players investigated in this study only played outdoor soccer on grass fields, while the players studied by Ekstrand and Gillquist[3, 9] played soccer on grass fields outdoors as well as in harder surfaces indoors. Hard playing surfaces might contribute to more overuse injuries than soft playing surfaces.[1]

There was a reinjury rate of 27.3% during the season. These injuries were mostly strains and overuse injuries of mild to moderate severity. This reinjury rate may be attributed to a poor medical knowledge of players and coaches in Edmonton soccer. Few players sought medical orientation to treat their injuries during the season. The players would usually treat themselves without any medical orientation. The same problem occurred in European soccer.[3, 9, 84] Amateur players usually treated their own injuries without medical orientation. This fact is a big concern in European soccer. Ekstrand and Gillquist[10] have pointed out the importance of a good rehabilitation program to avoid injury recurrence, because most major soccer injuries were caused by poor rehabilitation of a previous injury of minor or moderate severity.[10]

An unusual high rate of hamstrings strains (22.7%) was found in this study. Ekstrand and Gillquist,[3, 9] and Nielsen and Yde[84] found a hamstring strain rate of only 6.6% and 7.3% respectively. The reason, as mentioned above, may be the poor training of the players in this study, as the players might not have warmed up properly or at all before the games. In addition, the players would not perform stretching exercises often or at all during the season. Thus, only 14.4% of the players studied in this research had more than 70^0 of hip flexion. This finding reflects how poor the flexibility of these players was. Hamstrings strains do not cause the same dramatic consequences that knee injuries may cause in soccer. However, hamstrings strains tend to recur often if the injured player is not treated properly.[3, 9] Thus, there has recently been an increased concern about recurrence of hamstring strains in soccer.[86] A good physiotherapy program to treat hamstring strains has been shown to avoid injury recurrence in soccer.[86] In the present study, there was a 40% hamstring strain recurrence. Garret et al[87] observed that it was not uncommon to find calcifications in the inflammatory process of hamstrings strains. Garret et al[87] evaluated the healing process of hamstring strains in different athletes, including soccer players. It is possible that these calcifications found in the hamstrings of injured athletes, be responsible for many strain recurrences. Surgical procedures may be necessary to remove calcifications of injured muscles, a costly and time consuming treatment for many players. Thus, soccer coaches should encourage their players to do stretching exercises more often, to warm up before playing ball, and to seek medical orientation in any case of a hamstring strain.

5.1.3 Injury Circumstances:

Thirty six percent of the players were directly injured (by physical contact with another player), and 64% were indirectly injured (no physical contact with anybody or anything). This finding showed that soccer at the amateur level in Edmonton had minimal violence. In other words, few players were injured by tackles. Nielsen and Yde[84] reported similar results in Denmark: 30% of injuries caused by tackles. The small percentage of players injured by tackles showed that physical characteristics intrinsic to players (such as muscle tightness, muscle imbalance, and poor endurance) play a major role in the etiology of most soccer injuries (sprains, strains, and overuse injuries).

Of all injuries, 72.7% ocurred during the games and 4.5% occurred during practices. Overuse injuries (13.6%) did not have any specific traumatic occasion, because they had a gradual onset of symptoms. Ekstrand and Gillquist[3, 9] and Engström et al[85] found lower game injury rates (44% and 47% respectively) and higher practice injury rates (26% and 27% respectively) than the present author did. The reason may be attributed to a difference between the subjects studied by the present author and the subjects studied by the latter authors. The former investigated Edmonton players and the latter investigated European players. The level of soccer development in Europe is higher than that in Canada. In Europe, soccer has been played longer than in Canada. Professional soccer in Europe has been a tradition since the sixties, while in Canada, there are only a few teams of semiprofessional players. This increased soccer development in Europe may reflect higher soccer training intensities for European amateur players as compared to Edmonton amateur players. This statement may explain why Europeans had more injuries during practices than the Canadians studied. As well, European players may train more often than the Canadian players studied.

Among the injuries, only 9.1% were considered as major (one month or more time lost from play). This finding indicates that senior soccer played at an amateur level in Edmonton is relatively safe. Ekstrand and Gillquist[3, 9] reported similar rate of major injuries (11%) for amateur players who played soccer at the fourth division of the Swedish Soccer League. However, Nielsen and Yde[84] and Engström et al[85] reported higher rates of major injuries for Danish amateur players (35%) and Swedish semiprofessional players (29%) respectively. Injury severity was said to increase as soccer level raised.[85] Thus, the reason Engström et al[85] reported a higher rate of major injuries than the present author did, may be that the former evaluated semiprofessional players and the latter evaluated amateur players. However, it is not known why Nielsen and Yde[84] found higher major injury rate than the current author.

Knee injuries were responsible for all the major injuries in the current research. Similar results were found elsewhere.[3, 9, 84, 85] Ekstrand and Gillquist,[3, 9] Engström et al[85] and Nielsen and Yde[84] reported respectively 35%, 46% and 55% of all major injuries to the knee. These figures indicate the high incidence of major knee injuries in soccer. Seventy five percent of knee sprains in the current research were caused by tackles. Nielsen and Yde[84] and Engström et al[85] presented similar results, the former reported 55% of all knee injuries caused by tackles and the latter reported 50% of all major knee injuries caused by tackles. Tackles are considered as violations of soccer rules. Knee injuries may interrupt the playing ability of soccer players for years or even for good.[84, 85] Thus, it is essential that referees penalize foul plays strictly in soccer.

5.2 Soccer Injuries vs Range of Joint Motion

5.2.1 Muscle Strains and Overuse Injuries vs Hypomobility

This study attempted to determine whether hypomobility (associated with muscle tightness) could increase the risks of strain and overuse injury (tendinitis, bursitis) in soccer players. For this purpose, the players were tested for flexibility before the soccer season began. Four major muscular groups of the lower extremities (the quadriceps, the hamstrings, the groin muscles, and the triceps surae) were tested. During the season, seven muscle strains and three overuse injuries occurred. Of the muscle strains, five affected the hamstrings and two affected the groin muscles. Of the overuse injuries, one was an Achilles tendinitis, another was a plantar fasciitis, and the third was a bursitis over the first metatarsal head. Because the flexibility of the abductor hallux was not measured, the study of this bursitis was not further investigated.

There were only two groin strains during the soccer season. This small number of strains made it difficult to study the relationship between strains and hypomobile hip abduction. In addition, both strains affected players who had average joint mobility. Thus, it was not possible to say anything about the relationship between groin strain and muscle tightness.

Five hamstring strains occurred during the soccer season. Two strains affected players with hip flexion hypomobility and three affected players with average hip flexion mobility. No player with range of motion above 69° (hypermobility) suffered a strain. Forty percent of the injuries affected players with ROM below 55° (hypomobility). The number of hamstring strains that affected the latter players (40% of the injuries) were as many as two and a half times of what were expected (14.4%). This large number of injuries in athletes with poor flexibility indicated a strong association between strains and muscle tightness. These results strongly supported the theory that muscle tightness would predispose soccer players to muscle strains.

Ekstrand and Gillquist[3, 10, 11] agreed that tightness predisposed soccer players to strains. These authors reported that flexibility exercises could prevent muscle strains in soccer players.[11] As well, they found that soccer players who had at least one tight muscle in the lower limbs also had a higher risk of sustaining muscle strains than players without any tightness.[3, 10] The current study presented the relationship between muscle strains and tightness more clearly than the last study. According to Ekstrand and Gillquist,[3, 10] any muscle tightness in the lower extremities might contribute to any muscle strain in the lower extremities, despite any anatomical correlation. This statement was based on the finding that among 44 muscle strains and overuse injuries, 34 occurred in players with at least one tight muscle. Nevertheless, it was not explained how this fact could happen. It was difficult to understand how tightness in one muscular group could contribute to strain in another muscular group (quadriceps tightness could not have contributed to groin strain). Most soccer players (62.7%) studied by Ekstrand and Gillquist[3, 9, 10] had one tight muscle in the lower extremity. Tightness were usually found in the quadriceps, the triceps surae, or the groin muscles, but not in the hamstrings. However, 47.2% of all muscle strains affected the hamstrings, the muscular group which presented with the best flexibility among the muscular groups tested. While a smaller number of strains (14..4% to the groin muscles, 14.4% to the quadriceps, and 13.8% to the triceps surae) affected the muscular groups which usually presented with tightness. Hence, the relationship between tightness and strains could have been more clearly explained. Thefore, the current study complemented the results of the previous studies[3, 9, 10] in that it showed that hypomobility associated with tightness in a specific muscular group (the hamstrings) would contribute to strain in the same muscular group.

One player suffered an Achilles tendinitis and another suffered a plantar fasciitis during the season. Both players had average ankle dorsi-flexion. However, both players had ankle ROM below the mean value for the soccer players studied in this research, which may suggest that players who had lower ankle dorsi-flexion flexibility than their peers, also had a higher risk of overuse injuries than their peers. Nevertheless, care should be taken to consider these results, because of the small number of injuries seen in the present study. Ekstrand and Gillquist[3, 10] also found an association between overuse injuries and poor ROM in soccer. Nonetheless, as mentioned above, these authors[3, 10] did not demonstrate a clear relationship between the anatomical body part injured and the location of the tightness. In other athletic activities such as ballet, Reid et al[35] found iliotibial band tightness to be associated with overuse injuries at the lateral aspect of the hip and the knee. Reid et al[35] clearly demonstrated the anatomical relationship between tightness and injury. The previous findings[3, 9, 35] supported the relationship between tightness and overuse injuries found in the present research. The results of the present study as well as the findings of the latter studies supported the theory that muscle tightness would contribute to overuse injuries.

5.2.2 Ankle Sprains vs Hypomobility

Three ankle sprains (lateral ligaments) were seen during the season. Two sprains affected players with hypomobile ankle dorsi-flexion and one affected a player with average ankle dorsi-flexion. No player with ROM above 27^0 suffered a sprain. The number of sprains (66.6%) that affected players with ankle dorsi-flexion hypomobility were three times as many as that expected (17.7%), which suggested that good triceps surae flexibility not only prevented overuse injury and strain about the ankle, but also prevented ligament sprains at the same joint. This finding contradicts the suggestions made by other authors[30-33] that any hypermobile joint movement would contribute to sprains in any joint. These authors[30-33] believed that any hypermobility could contribute to joint sprains, basing their beliefs on the study published by Nicholas[28] regarding knee sprains only. As discussed previously in Chapter II (2.2.1 Hypermobility), the mechanism of sprains in the knee is different from that in the ankle. The ankle usually sprains in inversion, when the joint is plantar-flexed. Hence, because the calf muscles plantar-flex and invert the ankle, tight calf muscles may facilitate the positioning of the joint in an unstable position (plantar-flexion and inversion) and contribute to ankle sprains. The results found in the current study supported this latter theory.

5.2.3 Knee Sprains vs Hypermobility

Four players sustained knee sprains during the soccer season. There was a general trend among sprains to affect players with more joint mobility than their peers. The number of injuries which affected players with hypermobile knee flexion (50% of sprains) was almost three times as many as was expected (17.7% of sprains). In addition, 50% of knee ligamentous injuries affected players with hypermobile hip abduction, which was two and a half times as many as the number of sprains expected (19.3%). Based on the results of the current study, the hypothesis that knee hypermobility predisposed a soccer player to knee sprains was still not clear, mainly because very few knee injuries were seen in the study. In addition, knee sprains were evenly distributed among players with different ankle mobility. Furthermore, sprains also occurred in players with hypomobility, which contradicts the association between high risk of knee sprain and hypermobility. If knee hypermobility predisposed a soccer player to knee sprains, knee hypomobility would decrease the risk of knee sprains. Thus, the results of this study did not help to clarify the relationship between knee hypermobility and knee sprains.

5.3 Muscle Balance vs Injuries

Hamstrings/quadriceps strength ratio was measured at two different joint speeds: 30°/s and 300°/s. Hamstrings/quadriceps strength ratio was classified at each speed into low, average, and high. Subjects with muscle imbalance constituted players who had low or high strength ratio. Subjects with muscle balance constituted players who had average strength ratio. This study attempted to predict if muscle imbalance could predispose a soccer player to knee sprains or thigh strains.

Four knee sprains occurred during the soccer season, three sprains affected the medial collateral ligament (MCL) and one sprain affected the lateral collateral ligament (LCL). Three of the four sprains affected players who had a low strength ratio (below 53%) when measured isokinetically with gravity correction at 30°/s. This finding was one and a half times (75% of sprains) as many as was expected (45% of sprains) for players with a low strength ratio (46.8%), which might indicate a trend for knee sprains to occur in players who had a low strength ratio. This result meant that players who had hamstrings which were much weaker than the quadriceps were more susceptible to ligamentous injury than their peers. The stabilization of the knee depends on a good hamstrings/quadriceps reflex coactivation.[88] Good hamstring strength has been said to play an important role in the coactivation mechanism that protects high performance athletes from anterior cruciate ligament (ACL) tears.[88] Good hamstring strength may decrease the tension applied to the ligaments that resist anterior translation of the knee.[88] However, when the hamstrings is much weaker than the quadriceps, the ligaments that resist anterior translation of the knee are particularly susceptible to injury, because these ligaments do not have the same powerful reflexive hamstring contraction for their protection.[88] Besides the ACL, other ligaments contribute to resist anterior translation of the knee, among them: the MCL and the

LCL. The MCL resists mainly valgus stress at the knee, but it also play an important role in resisting anteromedial translation of the tibia on the femur. The LCL resists mainly varus stress at the knee, but it also plays an important role in resisting anterolateral translation of the tibia on the femur. The knee sprains observed in the current research happened when the players had their knee slightly bent and twisted. The ligament tears were probably caused by anterolateral or anteromedial dislocation of the tibia on the femur. When the knee was bent and twisted, hamstring contraction not only resisted anterior translation of the knee, but it might also have resisted valgus or varus stress on the joint, because of its angle of pull. Thus, hamstring contraction may have lowered the tension applied on the MCL and the LCL and decreased their injury risk. Therefore, hamstrings/quadriceps strength imbalance (low ratio) may contribute to ligament sprains. However, knee sprains were evenly distributed among players when their strength ratios were measured at 300°/s. Thus, based on the current study, the relationship between muscle imbalance and knee sprains was not completely understood.

Five hamstring strains were observed in this study. No quadriceps strains were seen in the study. There was a strong trend for hamstring strains to affect players who had a high strength ratio at both joint motion speeds tested in the study (30°/s and 300°/s). At 30°/s, the risk (20%) for players who had a high strength ratio to suffer a hamstring strain was 12 times that expected (1.6% of strains). Also at 30°/s, the number of strains (60% of muscle tears) that affected players who had a strength ratio above 60.8% were almost four times that expected (16.1% of muscle tears). At 300°/s, the risk (32.3%) for players who had high strength ratio to sustain a hamstring strain was two and a half times that expected (80% of strains). No strain affected any player who had a low strength ratio measured either at 30°/s or 300°/s. Therefore, the present study supported the theory that muscle imbalance would contribute to thigh strains. If a high hamstrings/quadriceps strength ratio contributed to a hamstring strain, the mechanism behind this fact is unknown. When the hamstrings flex the tibia, the quadriceps involuntarily contract to decelerate the flexion of the tibia in order to protect the joint (or vice versa).[54, 88] To stop knee flexion, it may be possible that the quadriceps could decrease hamstrings activity through a reflexive mechanism of inhibition. Hence, when the quadriceps is abnormally weaker than the hamstrings, the latter would not receive the same strong inhibitory action from the former. Thus, the hamstrings could produce an abnormal strong contraction and rupture its myotendinous junctions. As joint motion speed increased, the antagonists increased their muscle activity to improve limb deceleration.[54] As flexion/extension velocity increased, the quadriceps got weaker in relation to the hamstrings, (Table 4.5, Chapter IV). When joint motion velocity increased, the rectus femoris, semimembranous, semitendinous, and biceps femoris raised their electrical activity. However, the vasti (lateralis and medialis) did not raise their electrical activity.[89] The incompetence of some muscles which belong to the quadriceps to increase their activity during fast joint motion speeds may further raise the risks of hamstring strains, because muscle strains usually happen when athletes are performing fast cutting motions or running (both activities require fast joint motion speeds).[58] In the current research, 80% of hamstring strains affected players who had a high hamstrings/quadriceps strength ratio when measured at a fast joint motion speed (300°/s), which means that quadriceps strengthening, specially at high joint motion speed, may prevent hamstring strains.

5.4 Clinical Implications and Future Research

Flexibility testing was performed with a standard goniometer and the Myrin Goniometer®. The results of this study suggested that these instruments might have an important clinical role in measuring joint mobility. Detection of muscle tightness with these instruments might have prevented strains and overuse injuries (tendinitis) in soccer. The Myrin Goniometer® was found to be a reliable instrument to measure knee flexion, hip flexion, and ankle dorsi-flexion. Because of its ease in handling, the Myrin Goniometer® could be used quickly and accurately. It was a cheap instrument that did not require sophisticated information to be operated. Therefore, the measurement of joint mobility with the Myrin Goniometer® is highly recommended not only to prevent musculotendinous injuries, but also to evaluate joint mobility in the rehabilitation of diseases and injuries that affect joint motion. Nevertheless, the Myrin Goniometer® was designed to measure joint motions with the help of the gravitational force and thus, this instrument could not reliably measure joint motions in which the movements of the bones of a joint were parallel to the plane of the gravitational force.[37] Therefore, instead of the Myrin Goniometer®, the standard goniometer had to be used to measure hip abduction with the subject lying supine on a table (the femur and the pelvis were in a plane parallel to that of the gravitational force). The standard goniometer was a reliable instrument to measure hip abduction. As well, the standard goniometer was cheap and easy to handle. Hence, the standard goniometer may also be a useful tool to measure ROM. However, therapists should be more careful to use the latter instrument than the Myrin goniometer®, because the standard goniometer requires that therapists use precise body landmarks for its measurements, while the Myrin Goniometer® does not require the same body landmark precision.

The Cybex II® isokinetic dynamometer was used to measure muscle imbalance between the hamstrings and the quadriceps. The findings of the current research suggested that detection of muscle imbalance with the Cybex II® might have prevented knee sprains and hamstrings strains in soccer. In addition, this dynamometer could be clinically important to correct and maintain a good muscle balance between the hamstrings and the quadriceps in the rehabilitation of knee sprains and hamstrings strains of the players. If the Cybex II® were useful to prevent and treat knee sprains and hamstrings strains, other similar isokinetic dynamometers could also be useful to prevent and treat these injuries. Dynamometers such as the KinCon®, which provides gravity correction almost instantaneously with the measurement of muscle strength as well as automatic calibration, could be even more useful to clinicians because of its ease in handling.

This study investigated a small sample size. Hence, few injuries were seen during the season. Thus, future research should be done to confirm the findings of this study. In addition, this study investigated exclusively injuries associated with joint mobility related to muscle flexibility. It would be interesting to investigate soccer injuries associated with joint mobility related to ligamentous laxity. For example, ligamentous laxity could be measured with the arthrometer model KT-1000® (MEDmetric Corporation) at the knee and the results correlated to knee sprains.[59] Furthermore, this investigation studied exclusively the relationship between the hamstrings/quadriceps strength balance and soccer injuries. It would be interesting to investigate the relationship between the hamstrings/quadriceps endurance balance and soccer injures, because of the endurance demand required by soccer. As well, the relationship between muscle balance and sports injuries could be examined in contact sports (ice hockey, football, or basketball) other than soccer, because muscle balance may be sport specific and the hamstrings/quadriceps ratio may vary in different contact sports.

5.5 Medical Implications for Canadian Soccer Community.

The soccer injuries that were most often seen in this research, include knee sprains and hamstring strains. There was a trend among the strains to affect players who had muscle tightness as well as a high hamstrings/quadriceps strenght ratio at 300°/s. In other words, players with tight muscles and the hamstrings abnormally stronger relative to the quadriceps were more often injured than their peers. The great majority of the players in the Premier Division of the Edmonton Soccer Association did not perform flexibility exercises during the soccer season. Hence, the injured players had poor hamstrings flexibility. The finding that a high muscle strength ratio at 300°/s contributed to hamstring strains, suggested that quadriceps strengthening at high joint motion speeds might prevent hamstring strains. Hamstring strain recurrence was very high (rate of 40%), probably because of the poor rehabilitation knowledge of players and coaches. Besides making a player lose time from play and work,[1] the treatment of hamstring strains may be very costly. When a muscle strain calcifies, surgical approaches may be required to avoid injury recurrence. Therefore, it is suggested that whenever an injury (such as a hamstring strain) occurs, the injured player should seek medical advise regarding its treatment.

All major injuries seen in the current research were to the knee. Knee injury is considered to be one of the most disastrous soccer injuries,[85] not only because of its immediate medical cost[16, 24] and its debilitating effects on the playing ability of the players,[85] but also because it might contribute to chronic joint diseases (such as osteochondritis dissecans) long after the player stopped to practicing the sport.[90] Among the players who suffered knee injuries, 75% had muscle imbalance (a low hamstring/quadriceps strength ratio) when measured isokinetically at 30°/s. This finding suggested that hamstring strengthening might prevent knee sprains. The effects of ROM in knee injuries were not clearly understood and deserve further investigation. The most important finding concerning knee sprains seen in the present study was that, they were mostly caused by foul plays (tackles). Thus, soccer referees may play an important role in the prevention of knee injuries by strictly punishing players who do not respect the rules.

Knee sprains and hamstring strains affected players with muscle imbalance. The former affected players with a low strength ratio and the latter affected players with a high strength ratio. These results suggested that there was an optimal strength balance between the hamstrings and the quadriceps. Therefore, when soccer players train, the amount of work out for the hamstrings and the quadriceps should be very similar. The training should not emphasize one muscle group to the detriment of the other, unless a muscle imbalance has previously been detected.

This study attempted to investigate soccer injury prevention based on a sample of 62 amateur soccer players. Hamstrings strains and knee sprains had highest incidence among the observed injuries. The results of the study suggested that hamstrings strains could potentially have been prevented by hamstrings stretching and quadriceps strengthening. As well, the current investigation suggested that knee sprains could have been avoided by hamstrings strengthening and punishment of players who tackled their adversaries. In summary, most soccer injuries could have been prevented by detection and correction of muscle tightness and muscle imbalance before the season as well as stricter observance of soccer rules.

CHAPTER VI

CONCLUSION

This study investigated injury prevention in outdoor soccer. Sixty two players of the Edmonton Soccer Association were followed prospectively during one summer soccer season. Twenty two injuries were recorded during the season. A questionnaire designed to obtain injury information was filled out for each accident that happened during the season. The questionnaire gathered information regarding injury circumstances (situation: game or practice, physical contact: direct or indirect, and severity) and injury characteristics (incidence, location, and nature) from the soccer players. This information gave insight into some extrinsic causes (violation of soccer rules, poor soccer equipment, and poor warming up before playing ball) of soccer injuries. In addition to the questionnaire, each soccer player was evaluated for muscle strength balance and muscle flexibility of the lower extremities before the beginning of the season. The evaluation of flexibility and muscle balance was performed in an attempt to predict sprains, strains and overuse injuries (tendinitis) during the season. Injury prediction was partially achieved. In summary, the findings of this investigation were:

1. Hamstring strains, knee sprains, and ankle sprains were the most common injuries seen during the season.
2. During the season, the great majority of the players did not stretch themselves, nor did they warm up before playing. This fact might have contributed to a high incidence of muscle strains seen during the study.
3. Strains and overuse injuries (tendinitis) affected mostly players with muscle tightness.
4. Ankle sprains tended to involve players with tight calf muscles.
5. Knee sprains generally affected players with a low hamstrings/quadriceps strength ratio measured at 30^{0}/s.

6. Hamstrings strains affected mostly players who had a high hamstrings/quadriceps strength ratio measured at both 30°/s and 300°/s.
7. Knee sprains were not clearly associated with knee hypermobility.
8. All major injuries were knee injuries. Knee injuries were mostly caused by tackles (violation of soccer rules).
9. Hamstring strains accounted for 22.7% of all injuries. Of hamstring strains, 40% recurred during the season. Injury recurrence was probably due to a poor injury rehabilitation knowledge of coaches and players.

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Appendix A

Injury Report System

Soccer Injury Report

Player name:__________________ Age: ____ Team:____________
Phone Number: ______________ Coach: __________________

Player Podition Stricker ☐ Midfielder ☐ Backer ☐ Goalkeeper ☐

When did the injury occur?

Game ☐ Practice ☐ During Physical Conditioning ☐

First Half		Second Half			
0 to 15 min	☐	0 to 15 min	☐	Warming up	☐
15 to 30 min	☐	15 to 30 min	☐	Cooling down	☐
30 to 45 min	☐	30 to 45 min	☐	Other	☐

Injury Date:____________ Return to play (date):____________
Games Lost:____________ Practices Lost: ____________

Injury History

Kicking ☐ Tackled ☐ Collision ☐ Running ☐ Overuse ☐

Stretching ☐ Twisting ☐ Kicked ☐ Other ☐ No Injury ☐

Injury Nature and Localization

Specific Diagnosis: ________ ________ ________	Knee	Ankle	Foot	Hip	Quadriceps	Hamstrings	Lower Leg	Upper Extremity	Head	Spine	Other
Ligament Sprain											
Muscle Strain											
Contusion											
Laceration											
Fracture											
Dislocation											
Skin Abrasion											
Overuse Injury											
Infection											
Other											

General Comments:

Appendix B

Consent Form

Informed Consent for Soccer Injury Study

Testing procedures: You will be tested for flexibility of the lower limbs and perform an exercise test on an isokinetic dynamometer apparatus at the University of Alberta, in the Department of Physical Therapy, South West trailers, Room. The Myrin Goniometer® and the standard goniometer will be the instruments used to measure the flexibility. On the isokinetic apparatus, you will perform repeated bending and straightening of the knee as fast and as hard as possible. You may feel muscular soreness at the end of the test or delayed muscular soreness the next day. Risks of cardiac complications very seldom occur with healthy individuals. The chances of muscle strains are very low in the test. However, you will be promptly helped if any of this happens. You are advised that you can deny consent at any time or discontinue the test at any time without. prejudce.

Injury Report System: You will be followed for soccer injuries during one summer season. Any injury sustained in the season will be recorded with your help. Questions will be made concerning location, nature, mechanism, and causes of the injuries. Your name will not be cited in the study or any other scientific activity (such as medical meetings and seminar presentations), unless you give further authorization.

Benefits of the study: This study will attempt to investigate facts related to the causes of soccer injuries. The knowledge obtained from the research may help the prevention of soccer injuries. Your coach will receive one copy of your profile and instruction regarding injury prevention. You are free to take part in the study and you can deny consent if you wish. You may ask any questions regarding the study before signing the consent form.

Consent

I have read the above and I agree to participate in the study.

NAME:________________________ SIGNATURE:____________________

DATE:________________________ WITNESS:____________________

Appendix C

Normative Data

Table 15 - Normative Strength Balance Ratio

Authors	Subjects & Joint Motion Speed	Hams/Quads Ratio ± SD
Öberg et al	Soccer Players at 30°/s	60.8% ± 7.8
Grana and Stafford	Football Players at 300°/s	83.5% ± 10.8

Data obtained by Öberg et al[70] (N=208 players) for soccer players and Stafford and Grana[44] for football players (N=60 players). Ratios (hamstrings/quadriceps) represent the average strength between the dominant leg and the non-dominant leg for football players and right and left legs for soccer players .

Appendix D

Gravity Correction

Gravity Correction

The subject sat on the Cybex chair with the seat angle at 100°. Straps were used to stabilize the individual on the chair (see details on Chapter III, 3.4 Procedures: Strength testing). The dynamometer speed was set to 30°/s, and the chart recorder to 30 ft-lb and 25 mm/s. The subject was relaxed and from full knee extension (0°), the leg was allowed to fall freely until 90° of flexion. The weight of the limb ("X") was recorded, Figure D.1 (A). The peak torque produced by the subject ("Y") was recorded, Figure D.1 (B). In the same angle where the peak torque occurred, the weight of the limb was marked (X) and added to the quadriceps ("X + Y") and subtracted from the hamstrings ("X -Y"), Figure 10.

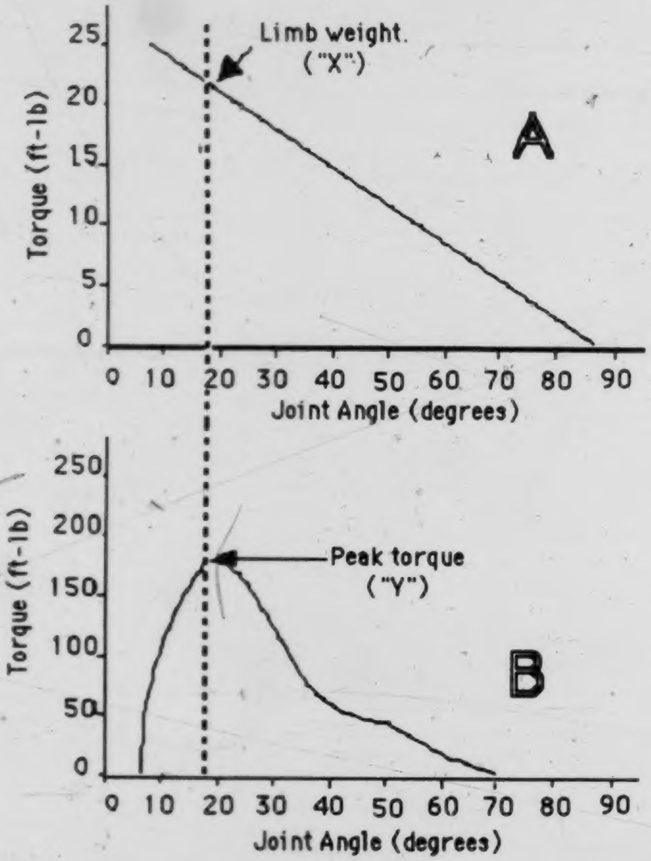

Figure 10 Cybex Chart Recorder. A: curve represents torque of limb weight. B: curve represents torque performed by the subject.

Appendix E

Cybex Calibration

Table 16 Cybex Calibration

Recorder Scale Selector	Lever Arm Inches*	Weight (Pounds)	Calib. Torque Input Foot-Pounds	Chart Recorder Peak Torque
360	30	70.0	180	5 major divisions
180	31	32.5	90	5 major divisions
30	33	5.0	20	20 major divisions

*Distance of center of Cybex input shaft to T tube (lever arm length).

For each recorder scale selector (360, 90, or 30)), a specific lever arm length (30, 31, or 32) and specific weight (70, 32.5, or 5 lbs) are adjusted to yield a specific torque output (180, 90, or 20 ft-lbs) on the chart recorder (5 or 20 major divisions), (Table 16).[76] For example, with the recorder scale selector at 360, the lever arm length should be adjusted to 30 inches and 70 pounds adjusted on the T bar should yield 180 ft-bls on the chart recorder (5 major divisions).

Procedures:[76]

1. Select recorder scale (360, 180, or 30). Adjust dynamometer speed to 30°/s, but do not apply torque to input shaft:

(a) adjust #3 on damping control.

(b) adjust chart recorder speed to 2 mm/s.(c) Using zero adjust control, align stylus with baseline of chart paper. Baseline shift may be corrected with with a small screw driver behind the cap marked Zero on the front vertical panel of the recorder case. A small division above or below the baseline on the scale is acceptable.

2. Attach proper amount of calibration weight. Lift the T bar manually from the ground until it passes the vertical position above the dynamometer. Then, allow the T bar to swing freely until it contacts the floor. Check on the chart recorder if the yielded torque is what was wanted (20 or 5 major divisions). If corrections are needed, adjust the proper potentiometer (30, 90, or 360) with a screw driver behind the plug on the front case of the recorder. Turning the screw driver clockwise decreases the reading and counterclockwise increases it.

Appendix F

Raw Data

F.1) Range of motion in degrees (values are average between left and right legs)

Players	Hip Abduction	Hip Flexion	Knee Flexion	Ankle Dorsi-flexion
1	42	68	140	27
2	46	78	130	24
2	44	66	135	23
3	46	62	136	20
4	35	51	138	21
6	47	61	160	30
7	40	67	137	20
8	40	64	148	19
9	40	71	133	23
10	50	67	159	29
11	49	70	153	35
12	46	58	146	25
13	50	65	142	26
14	39	75	129	18
15	46	60	133	20
16	38	65	142	21
17	46	52	137	23
18	44	52	143	26
19	42	53	135	16
20	44	62	136	21
21	53	63	153	28
22	41	70	138	25
23	35	60	132	26
24	45	58	143	29
25	38	55	132	31
26	47	68	146	22
27	38	60	143	20
28	46	66	157	23
29	44	44	146	15
30	40	67	145	31
31	39	59	147	26
32	46	71	157	30
33	38	68	133	19
34	50	55	150	25
35	52	69	157	27
36	36	56	131	17
37	44	47	149	20
38	38	56	152	25
39	36	62	151	20
40	38	59	148	15
41	51	62	160	25
42	46	68	139	17
43	48	53	151	22
44	48	66	147	24

Players	Hip Abduction	Hip Flexion	Knee Flexion	Ankle Dorsi-Flexion
45	46	69	133	20
46	38	63	144	19
47	44	59	134	24
48	50	61	146	21
49	50	58	145	22
50	42	57	139	18
51	40	59	146	15
52	38	66	142	20
53	30	62	129	12
54	45	55	131	17
55	52	50	141	24
56	46	64	133	15
57	46	58	143	17
58	42	69	134	11
59	51	51	141	19
60	38	60	138	18
61	48	67	134	24
62	52	78	156	28

F.2) Hamstrings/quadriceps Strength Ratio (CG: Gravity Correction)

Players	Ratio 30^0/s GC	Ratio 300^0/s GC	Ratio 30^0/s	Ratio 300^0/s
1	0.628	0.670	0.729	0.963
2	0.519	0.763	0.576	1.000
2	0.496	0.549	0.593	0.806
3	0.507	0.568	0.567	0.841
4	0.668	0.532	0.757	0.767
6	0.360	0.563	0.427	0.795
7	0.471	0.549	0.551	0.857
8	0.510	0.580	0.615	0.758
9	0.550	0.680	0.600	0.971
10	0.455	0.683	0.538	0.943
11	0.526	0.636	0.646	0.889
12	0.631	0.667	0.714	0.883
13	0.535	0.753	0.607	0.957
14	0.405	0.661	0.457	0.836
15	0.311	0.514	0.387	0.736
16	0.603	0.727	0.689	0.940
17	0.449	0.786	0.523	0.952
18	0.723	0.821	0.814	1.059
19	0.576	0.647	0.672	0.979
20	0.534	0.820	0.604	1.038
21	0.605	0.690	0.678	0.872
22	0.534	0.594	0.587	0.729
23	0.573	0.688	0.655	0.944
24	0.429	0.620	0.493	0.824
25	0.463	0.541	0.529	0.753
26	0.479	0.573	0.524	0.845
27	0.500	0.765	0.578	0.952
28	0.623	0.805	0.729	1.038
29	0.582	0.480	0.679	0.667
30	0.604	0.769	0.676	0.909
31	0.585	0.748	0.659	0.911
32	0.522	0.660	0.621	0.884
33	0.585	0.685	0.645	0.905
34	0.513	0.626	0.571	0.795
35	0.427	0.724	0.492	0.895
36	0.590	0.727	0.667	0.933
37	0.553	0.750	0.611	0.951
38	0.519	0.584	0.590	0.807
39	0.551	0.718	0.629	0.898
40	0.488	0.694	0.545	0.807
41	0.476	0.728	0.529	0.950
42	0.558	0.636	0.643	0.804
43	0.505	0.552	0.566	0.712
44	0.387	0.640	0.434	0.821
45	0.643	0.716	0.727	0.918

Players	Ratio 30^0/s GC	Ratio 300^0/s GC	Ratio 30^0/s	Ratio 300^0/s
46	0.512	0.587	0.580	0.841
47	0.621	0.728	0.722	0.943
48	0.539	0.772	0.608	0.932
49	0.463	0.665	0.542	0.881
50	0.570	0.774	0.630	0.990
51	0.533	0.763	0.585	0.915
52	0.640	0.540	0.724	0.780
53	0.649	0.706	0.742	0.863
54	0.580	0.752	0.630	0.925
55	0.581	0.873	0.653	1.139
56	0.598	0.796	0.690	1.000
57	0.473	0.589	0.532	0.748
58	0.664	0.718	0.745	0.905
59	0.505	0.585	0.567	0.769
60	0.503	0.752	0.577	0.976
61	0.566	0.677	0.623	0.826
62	0.503	0.636	0.561	0.787